POSITION A1

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LLOYD'S REGISTER STAFF ASSOCIATION.

Remarks by the President, R. B. Shepheard, Esq., B.Sc.

Gentlemen,

This is a great occasion in the history of our Association. After an interval of seven and a half momentous years we meet together again in this room for the reading and discussion of a paper by one of our members—the first in our programme for the Session 1946–47.

I thank you for the honour you have done me in electing me to be your President, an office which has been held by a succession of respected members of the Staff of Lloyd's Register. I shall do my best to assist in maintaining the traditions of our Association.

For we have great traditions. The inaugural meeting of the Staff Association was held in October, 1920, when J. T. Milton read a paper on "Measurements of exceedingly large and extremely small quantities." During the ensuing years, up to the outbreak of the recent war, about six papers have been presented during each winter session by members of the Staff. It is well worth while, particularly for our more junior colleagues, to make time to peruse the Volumes of the Association's Transactions. These are of absorbing interest and value, covering as they do a full range of subjects—theoretical and practical—general and specialised—in the wide sphere of our professional interests. The papers have been prepared by enthusiasts, expert in their subjects, and have generally provoked keen discussion—a sound indication of the merit of most technical papers.

Special lectures by external authorities on a variety of topics of more general interest have also been presented to the Association.

We may justly be proud of the high standing and reputation of our own Technical Institution.

But that is not all. The Association constitutes a forum for the dissemination and exchange of information and experience in our calling among colleagues at home and abroad, and between "Old Hands" and "New Boys."

Those of us who have served in far places have derived, through the Association's activities, help and stimulation in our comparative isolation. I would especially ask younger members to participate wholeheartedly in our deliberations; they have much to contribute as well as to gain.

Your Committee and Secretary have prepared a full programme for the coming Session. We are to have papers of topical interest from authors who have found time for the preparation of them under the present busy conditions. We are grateful to them for the promise of good fare.

With the active interest of members, wherever they may be stationed, we can look forward with confidence to a period of renewed activity for Lloyd's Register Staff Association.

PRIVATE AND CONFIDENTIAL.

G. O. Walton

LLOYD'S REGISTER STAFF ASSOCIATION.

SESSION 1946-47.
PAPER No. 1.

SURVEY OF MASS PRODUCTION.

By P. T. BROWN, M.B.E., M.C.

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LONDON, E.C.3.

Dimensional accuracy

The Author of this paper retains the right of subsequent publication, subject to the sanction of the Committee of Lloyd's Register. Any opinions expressed and statements made in this paper and in the subsequent discussion are those of the individuals.

SURVEY OF MASS PRODUCTION.

IT is not proposed in this paper to deal with the detail of mass inspection, its purpose being rather to suggest a system for the co-ordination of Works' facilities with the Society's practice to constitute an appropriate technique for the *survey* of plant or machinery manufactured on mass production lines. Practical methods of inspection and the use of precision measuring equipment are the subject of quite good little books* published in recent years, and the new technique applicable to mass inspection known as Quality Control is well summarized in B.S.S.1008–1942. On the organisation side the paper on Inspection of Aircraft by Mr. L. J. Hill read to this Association in 1931 gives valuable information.

The Society's Rules for the Construction and Survey of Machinery require that it be "*inspected* throughout" and specifies that "the Surveyors examine the materials and workmanship from the commencement of the work until the final test of the machinery; any defects are to be pointed out as early as possible". Where "Freehand" methods of construction are employed these requirements can be met by visiting the Works twice or, at most, three times per week and making a round of the machines and benches engaged. The tempo of mass production requires a more organised system to retain the effective control implied by the Society's Survey.

Before dealing with the question of a workable technique to meet the modern trend of manufacture, it is thought well to consider the terms "inspection" and "survey" and to define the functions of Inspector and Surveyor. "*Inspection*" is a particular function of limited responsibility, mostly dimensional, applicable to specific detail, and the Inspector will be a specialist competent to decide whether an item of detail is correct from the manufacturing aspect, but he need not know anything of the purpose for which the detail is intended. "*Survey*" is a general function of control involving full responsibility, and the Surveyor should be an experienced Engineer conversant with the purpose of the machinery under construction, who also combines a lively appreciation of manufacturing methods and difficulties, with a good knowledge of materials and sound judgment of workmanship. In short, the Inspector says whether a part conforms to drawing and the Surveyor decides whether it will do the job and takes the ultimate responsibility.

An efficient Inspection Department is an essential feature in the organisation of Works producing on mass lines; a fact which may eventually involve consideration being given to some system of Approved Inspection. In the meantime, survey technique should be adapted to take advantage of the facilities provided. In doing this it is most important not to convey the impression that the survey is in substitution of Works' Inspection—such a viewpoint would be disastrous—and the Inspectorate should understand their functions are not usurped and that their co-operation is desired and will be reciprocated.

MATERIALS.

A defect in material will soon be noticed by a craftsman making a single article and it will be scrapped with loss of material only. Things are not so simple in mass-production. Operators have little appreciation of what constitutes a defect with the result that faults may not be discovered until quite a lot of machine time has been lost and possibly the even flow of production affected. It is accordingly most important that the greatest care be taken in the inspection of raw materials.

Steel Bar Material, &c.

Unless specifically required the Society's Surveyors, in the normal course of their duties at Steel Works, only give attention to surface, section, and gauge when the test pieces indicate a fault. It is therefore desirable that manufacturers ordering materials to be used in mass production specify surface inspection and indicate gauge limits. They should also state the colour or other identification markings required, and when material is to be dealt with by "automatics" the fact should be mentioned.

* "Engineering Inspection".—Parkinson. "Limits and Fits for Engineering, B.S.164". "Engineering Inspection Practice".—A. T. King.

Castings.

In the ordinary practice of the Society notice is not taken of iron or brass castings until the machining stage, but for the above-mentioned reasons it is desirable in mass production that they be examined at the foundry. Particular attention should be given to the first casting made from a pattern and it should be marked off to ensure that machining allowances are satisfactory and then sectioned to prove metal thicknesses, the correct position of cores and that all sand and core wires are removed. Not until it is established that the casting is satisfactory should production proceed. Whilst subsequent castings can be passed on visual examination, it is advisable to have suitable gauges or jigs made for checking vital dimensions. Whenever a pattern is renewed the foregoing procedure should be repeated.

Forgings.

It is normal practice to inspect all principal forgings at the place of manufacture; for mass production this service will be extended to cover many of lesser importance. Drop stampings involve procedure akin to that mentioned above for castings. The dies should be proved before starting to forge and the first stamping should be marked off and subsequently sectioned before bulk production is started.

Processing.

Works organisation is of more than passing interest to the Surveyor. Having to take much for granted, he should feel satisfied with the processing and methods of control in progress so that in taking the responsibility of certifying the product, he is not involving himself or the Society in unjustifiable risks. The department of first interest is the Stores, whose methods of reception, storage and issue of materials should satisfy the following requirements:—

(1) That Lloyd's inspected material is bonded or segregated to prevent the possibility of it being mixed with similar material.

(2) That various sizes and grades are separate and the latter, by colour markings, are readily identifiable.

(3) That various consignments are kept separate.

(4) That receipts and issues are recorded on cards attached to the racks or bins.

It should also be arranged with the Storekeeper that materials are issued in the order of receipt and that no consignment is broken into until the previous one is used. Care exercised in the storage and issue of materials must not be negatived during production and the progress system should permit of identification of material through all stages of machining, so that in the event of a defect being found, effective action to clear suspect material from "the line" may be taken. Appropriate notation on the job card will ensure this.

Machining.

Machining operations in repetition work involve the use of jigs, and, whilst the style and design of such is the manufacturers' business, the Surveyor should be satisfied that consistently accurate products will result from their use. The first part machined off a new jig should be meticulously checked.

Jigs are subject to wear, and the Works' organisation should provide for their periodic inspection. If this is not a matter of strictly observed routine, special arrangements should be made that jigs used for work to the Society's survey are returned to the toolroom for calibration and correction at agreed periods dependent on their usage.

Heat Treatment.

Heat Treatment processes, being much employed in modern engineering practice, demand particular consideration. As variations in temperature and times to attain the requisite characteristics vary with the grades of steel, a strict control is essential, and this is best effected by the use of cards or a register in which the operator is required to record full particulars of the treatment given. These cards or register pass with each batch of material to the Inspection Department, which will enter against each record the numerals obtained by hardness tests. These records will be subject to the Surveyor's scrutiny,

as will dial cards of recording pyrometers where such are installed.

Where case-hardening is employed samples should be selected from time to time and either broken or step ground to verify that the requisite case depth is being maintained.

Schedule of Operations.

For manufacture in mass the sequence of operations is planned and the machines to be used are designated by the Planning Engineer's Department and a Schedule of operations issued. The Surveyor should be satisfied the machines are appropriate to the job and that the sequence is not such that there is liability of error in the finished product.

Floor and Intermediate Inspection.

In larger factories a partial inspection is carried out through the stages of machining to eliminate possible wastage of machine time. It is well to take an interest in this work and to co-operate with the staff engaged.

Final Inspection of Details.

Works' inspection departments should be equipped with micrometers, vernier calliper and height gauges, scribing blocks, Mercer dial and cylinder gauges and, to keep up with the tempo of production, limit gauges of Go ond No Go type should be provided for the quick checking of particular dimensions. For many details of machinery it is desirable that special measuring jigs be provided to prove the relationship of the various dimensions. The Surveyors should collaborate in the design of such fixtures to satisfy themselves that all requirements are met.

Works' organisation should provide for the periodic calibration of all instruments, gauges and measuring jigs.

Records should be kept by the Inspection Department which identify material to its source, state quantities accepted and rejected and give the reasons for rejection. For more important parts vital particulars should be recorded on tabulated schedules by the Inspector. Examples of such schedules are given in Appendix 2.

Dependent upon the equipment provided, the organisation and quality of Inspection Staff and the mutual confidence established, the survey control will be formulated. Simple parts may be accepted on, say, full measurement of a small percentage, check measurement of others and visual examination of a further number; the extent of detailed attention naturally varying with the importance of the part concerned and experience. For more important parts the Inspector's schedules should first be examined and parts selected for full or partial examination, according to the particulars recorded. Border line cases, to which the Inspectorate should be required to draw attention, will receive 100 per cent. inspection.

To avoid misapprehension it may be well to call attention to the fact that acceptance of a quantity of articles on a percentage inspection does not limit responsibility to those personally checked.

Inspection Scrap.

It is customary in many Works to hold "inquests" on parts scrapped by the Inspectorate. This is sound practice and, where not already a routine affair, Surveyors should recommend it. There are two primary objects involved: (1) To consider the possibility of rectification and (2) To ascertain the cause which has rendered the part unserviceable and to suggest how repetition of the fault can be prevented. Both are interests of the Surveyor, who should therefore join in these enquiries as often as can be made possible.

Assemblies.

Whilst the principles involved in the *inspection* of parts are applicable to assemblies, the work at this stage may be more aptly designated *survey*. To ensure control and that nothing vital is overlooked, the Surveyor should personally examine the job at certain definite stages in assembly and arrange for the Inspectorate to check such things as alignment and clearances and to record the data obtained for verification.

Final Testing.

Final testing being specifically mentioned in certificates is a major consideration. The Society specifies the tests on which it is prepared to grant its certificate, consequently the Surveyor has a definite responsibility to see that the results are

satisfactory. But, in mass produced work, he cannot personally watch every test through; he must therefore be completely satisfied with the testing equipment, the personnel engaged and the recording of data. As far as possible the starting and/or stopping of tests should be seen, and in all cases visits should be paid during the test and records verified. All special tests, e.g., overloads, governing, manœuvring, &c., should be witnessed.

Identification.

Important forgings and castings should carry the makers' batch numbers throughout, the markings being transferred when removed by machining operations. The Surveyor's stamp will be added to these marks after final inspection, and, when hydraulic tests are made, particulars of such should be stamped on the tested detail. It is desirable that each forge or foundry adopt serial markings with prefix letters identifying the firm and that these markings are in a certain specified position verifiable on the completed assembly. Small items and items of lesser importance do not require a serial number, but each detail passed must bear the accepting inspector's stamp.

Reporting.

Manufacturers producing machinery by mass methods, besides purchasing their raw materials, have usually the help of sub-contractors for specialised detail, and much of this detail will require inspection at the Works where made and will have to be reported. Such reports should be of standardised form which may, in the case of some details, take the form of release or advice notes. For principal structural items and working parts certain technical data will have to be recorded and special report forms needed. Whatever form they take, the necessity for prompt compilation and issue of reports cannot be over emphasized. Unless release or advice notes are available to the consignee when stores are received inconvenience is certain to be caused, and if delays are appreciable the tempo of production may be seriously affected. The desired results will only be achieved by a close liaison between Inspection and Despatch Departments and it is accordingly a matter of interest to the Surveyor that arrangements between these departments function satisfactorily.

Whilst the extent and scope of reporting will vary somewhat with the job, and may need adjustment to suit the clients' or manufacturers' requirements, the following is necessary:—

(1) Materials, Forgings and Castings.

Release or advice notes and reports quoting results of tests and other technical data required. Copies of these will be required by the machinist and surveyor dealing with machining.

(2) Machined Parts and Components.

Release or advice notes and, in certain cases, reports giving technical data. These reports will quote the origin of material and relevant reports. Copies of release notes to consignee and surveyor concerned and of Technical Report to surveyor.

(3) Assemblies.

Reports in which the Surveyor will make his recommendations and give all necessary information for the issue of certificate. These reports should, by reference to relevant detail reports, give information which will enable vital details to be traced back through all stages of manufacture.

Compilation of these reports is made a simple matter by the use of printed forms on which the required data is entered in appropriate columns.

Conclusion.

The technique involved for effective control of mass production can be summarised as involving a close co-operative relationship with Works' organisation—Stores, Planning, Jig and Tool Room, Production, Inspection and Despatch—and adaptation of Works' system to meet the Society's requirements. Planning of the survey to suit the circumstances of each particular job should be done by a Central Department which will distribute orders and sub-orders for materials and parts, receive all detail reports, co-ordinate the work between the contractors and make decisions on concessions.

Clerical duties associated with manufacture in great quantities are more extensive than obtained in more loosely organised work, and, the same condition applying to the survey, results in some increase in the cost of inspection. In this connection it must be mentioned that, although the costs of inspecting detail are lower when large quantities are dealt with, the ratio of Inspection to Production costs is greater.

Engineers, whilst admitting the economic advantage of mass production, lament the displacement of the craftsman, so thoroughly reliable and interested in his job, by the semi-skilled operator. But he has not disappeared and is much in evidence in the toolroom, which gives full scope for his ingenuity and mechanical skill. Referring to the "operator", Mr. Colm Brogan, in his "Democrat at the Supper Table", recognises an advantage to society in general in the way mass production has enabled all sorts of people who, in the days when more individual skill was necessary, would have lived under perpetual fault-finding, to be of value to the community. He writes "We have the sad army of utter incompetents, the handless, dilatory hazy-minded men who, in other days, were never taken on even for the most mindless job except in rush times, and then only with a sigh; the clumsy depressed waitresses in shabby cafes who slopped about spilling tea for the wrong customer, getting the change wrong or forgetting the bill; the domestic servant who broke every dish she handled and couldn't wash a floor, or even tell whether it was dirty or clean. The robot-factory gives these men and women, who have a right to live, some chance of living decently."

Appendix 1.

SUMMARY OF THINGS

To know :—

1.—The construction and operation of the machinery or plant being built under survey, even though only concerned with a detail.

2.—The materials being used, their mechanical characteristics and the tests to be imposed; also why such materials have been chosen.

3.—The dimensional limits applicable and the discretionary tolerances which might be granted, and in what circumstances.

4.—The grade of workmanship needed for successful operation.

5.—The acceptability of rectification of faults and the extent to which such may be permitted and the methods which may be used.

6.—The Works' organisation and responsibilities of the officials.

7.—The jigs and tools in use for production and inspection.

To do :—

1.—Explain scope of Surveyors' duties and the Society's requirements to the Management and invite its co-operation.

2.—Arrange with "Stores" for the segregation or bonding of materials and components accepted by the Society and intended for jobs in hand.

3.—Arrange with "Production" for tracing of materials through process and for heat-treatment recording.

4.—Arrange with Chief Inspector for details of inspection and ensure effective liaison.

5.—Arrange with "Despatch" regarding Release or Advice Notes.

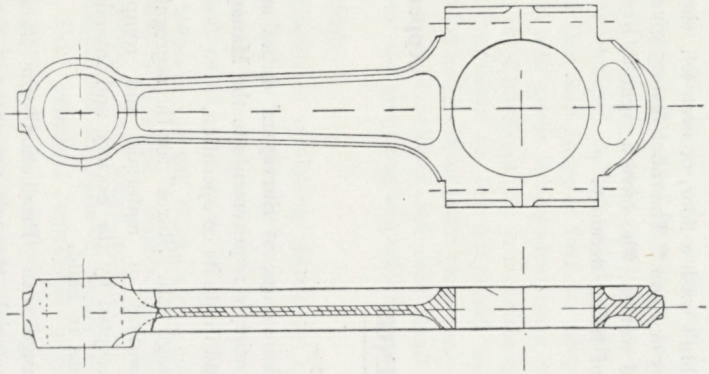
6.—Arrange with Management for "Inquests on Scrap."

7.—Arrange with "Production" and "Inspection" for periodic checking of machining and inspection jigs.

Appendix 2.

CENTRE CONNECTING ROD.

CONTRACT No. .....



LIMITS.

BORE B.E. ... 5" $^{-.000}_{+.0015}$

" S.E. ... $2\frac{3}{4}$" ± .0004

LENGTH, CRS. ... 16" ± .002

WEIGHT. B.E ... 14 lbs 6oz ± 1lb 2oz

" S.E. ... 7 lbs 7oz 2s ± 1oz

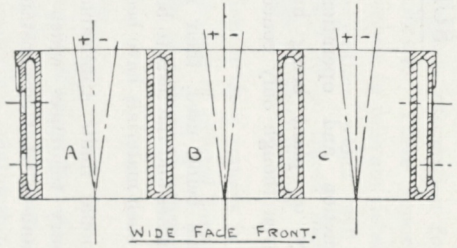
" TOTAL ... 21 lbs 13oz 2s ± 2oz

BOLT HOLES .... $\frac{3}{4}$" $^{-.000}_{+.0005}$.

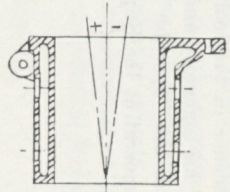
WORKS No.	LLOYDS FORGING No.	LLOYD'S SET No.	LENGTH	TOP & BOTTOM BORES		WEIGHT. B.E.	WEIGHT. S.E.	WEIGHT. TOTAL.	BORE. B.E.	BORE. S.E.	BOLT HOLES.	MAGNETIC CRACK DETECTOR.	REMARKS.
				PARALLELISM.	TWIST								

CYLINDER BLOCK

CONTRACT No .....



WIDE FACE FRONT.



WIDE FACE RIGHT.

LIMITS.

BORE ... $\{ ^{+.000}_{-.001}$

PARALLELISM ... L ± .002"

" ... A ± .005"

HEIGHT ... ± .0025"

SPIGOT ... ± .001"

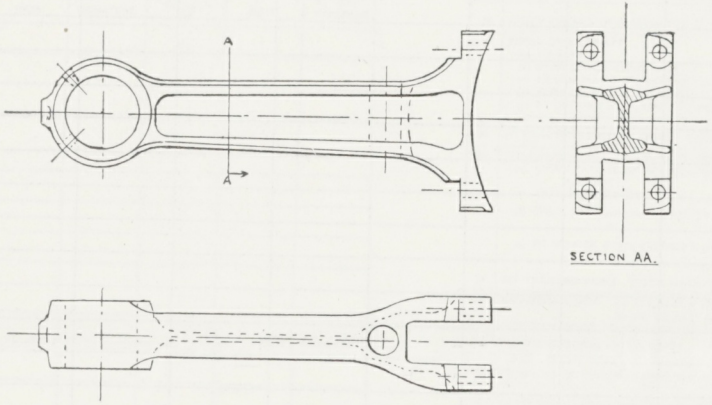
TOP FACE .... −.0025"

WORKS No.	LLOYD'S SERIAL No	BORE DIAMS.			PARALLELISM OF BORES,						HEIGHT.	SPIGOT DEPTH.	FLATNESS TOP FACE.	REMARKS.
					LONGITUDINAL + OR −			ATHWART + OR −						
		A	B.	C.	A	B	C	A	B	C				

Appendix 2.

FORKED CONNECTING ROD.

CONTRACT No. . . . . .



SECTION AA.

LIMITS.

BORE S.E. ..... $2\frac{3}{4}$" ± ·0004
FORKED RADIUS ... $7\frac{1}{16}$"
LENGTH (CENTRES) .. 16" ± ·002
BOLT HOLES .... $\frac{9}{16}$ $^{+\cdot 000}_{-\cdot 0005}$ DIAM.

WEIGHT (COMPLETE WITH BE. BEARING)
" S.E. ..... 8 lbs 4 ozs. ± 1 oz.
" B.E. ..... 20 - 8 " . ± 1½ ozs.
" TOTAL .. 28 - 12 " . ± 2 ozs.

WORKS No.	LLOYD'S FORGING No	LLOYD'S SET No.	LENGTH (CENTRES)	TOP BORE & FORKED RADIUS		WEIGHT. B.E.	WEIGHT. S.E.	WEIGHT TOTAL.	FORKED END RADIUS	BORE S.E.	BOLT HOLES.		MAGNETIC CRACK DETECTOR	REMARKS.
				PARALLELISM	TWIST.						SIZE.	SYMMETRY		

Appendix 3.

SPECIALLOID LTD.

INSPECTION REPORT ON .....PISTONS, BATCH..... Date.....

OPERATIONS	PISTON NUMBERS												
Ring Groove Positions ..													
Ring Groove Widths ..													
Ring Groove Diameter ..													
Drilling													
Boss Face Widths													
Circlip Widths													
Circlip Diameter													
Circlip Position													
Gudgeon Pin Bore Dia. ..													
Compression Height ..													
Skirt Length													
Cut Out Position Parallel to Bore													
Pot Position Parallel to Bore													
Throat Position Parallel to Bore													
Cut Out Position Right Angle to Bore													
Pot Position Right Angle to Bore													
Throat Position Right Angle to Bore													
Pot Depth													
Cut Out Depth													
Skirt & Lands Diameters ..													
General Foundry Finish ..													
General Machine Finish ..													
Weight													

Appendix 3.

ERECTION AND INSPECTION STAGE CARD

NAME OF FOREMAN..... UNIT ASSEMBLIES.

GEAR BOX NUMBER..... TYPE.....

Stage No.	OPERATIONS AND INSPECTION.	R.H. Unit No.	DATE.	SIGNATURE.	L.H. Unit No.	DATE.	SIGNATURE.
1	**CASING** : STUDDING AND INTERNAL PAINTING						
2	BEDDING OF SECONDARY SHAFT BEARING BUSHES						
3	FIT OF PRIMARY SHAFT BEARING... ...						
4	**SECONDARY SHAFT** : (a) FIT KEYS ... ... (b) PRESS ON GEAR ... ... (c) FIT OIL SEAL AND INTERMEDIATE BEARING						
5	**CLUTCHES** : (a) DE-BURR ... (b) CHECK POSITION OF PORTS ... (c) FIT TO SECONDARY SHAFT ... (d) CHECK END FLOAT (e) CLUTCH TRAVEL STATED OVERLEAF						
6	CLEAN OUT OIL HOLES IN SECONDARY SHAFT, FIT THRUST PLATES, CLUTCHES, FORWARD BEARING BUSHES AND END NUTS						
7	**PRIMARY SHAFT** : (a) FIT KEYS ... ... (b) PRESS ON GEARS ... ... (c) FIT BEARINGS, DISTANCE PLATES...						
8	**IDLER SHAFT** : CLEAN OIL HOLES AND CHECK CLEARANCE OF GEAR BUSH						
9	SPLIT CASING AND FIT PRIMARY, SECONDARY AND IDLER ASSEMBLIES : (a) CHECK LOCKING OF END NUTS ON PRIMARY AND SECONDARY SHAFTS ... ... (b) CHECK TOOTH CLEARANCES : (1) AHEAD ... ... (2) ASTERN						
10	**FIT PRESSURE OIL PUMP** : (a) CHECK ALIGNMENT ... ... (b) CHECK LOCKING OF ALL NUTS & PLUGS						
11	**FIT OIL SEAL TO PRIMARY SHAFT** : CHECK CLEARANCE						
12	**FIT DISTRIBUTION HOUSING** To SECONDARY SHAFT						
13	STAMP SERIAL NOS.						
14	TEST UNITS						
15	FIT AFT END BEARING, END NUT AND LOCKING WIRE TO SEC. SHAFT... ...						
16	CLEAN AND PAINT OUTSIDES OF CASINGS, ETC.						

Signature of Lloyd's Surveyor.....

MAIN ASSEMBLY

Stage No.	OPERATIONS AND INSPECTION.	DATE.	SIGNATURE.
17	**MAIN CASING** : STUDDING AND INTERNAL PAINTING		
18	CHECK BEDDING OF BEARING BUSHES FOR FINAL DRIVE SHAFT		
19	**FINAL DRIVE SHAFT** : (a) FIT KEYS ... ... (b) PRESS ON COUPLING ... ... (c) FIT GLAND RING, STUFFING BOX, AFT END BEARINGS AND BEARING BUSH... ... ... (d) PRESS ON FINAL DRIVE WHEEL ... ... (e) FIT DISTANCE PIECE, REAR BEARINGS, AND END NUTS		
20	FIT FINAL DRIVE SHAFT TO CASING. TIGHTEN AND LOCK END NUTS		
21	**FIT CLUTCH CASINGS TO MAIN CASING** : (a) CHECK PARALLELISM BETWEEN BOTTOMS OF CLUTCH CASING AND MAIN CASING. R.H. UNIT : L.H. UNIT : (State Thickness of Shim) (b) CHECK BACKLASH IN FINAL DRIVE : ... ... L.H. : R.H. : (c) FIT FITTINGS, BOLTS, DOWELS & SHIMS		
22	**FIT TRAILING PUMP** : CHECK ALIGNMENT		
23	**CONTROL COCK** : (a) CHECK FOR CORRECT FUNCTIONING ... ... (b) FIT TO MAIN CASING		
24	**FIT OIL COOLERS** : COOLER NOS.		
25	**FIT SUCTION AND DISCHARGE PIPES TO PRESSURE PUMPS : LOCK SCREWS**...		
26	FIT TEE PIECES AND MAIN SUCTION FILTERS : LOCK NUTS		
27	FIT 3-WAY COCK, NON-RETURN, 4 RELIEF VALVES...		
28	FIT PRESSURE FILTERS, TRAILING PUMP FILTER, AND DIP STICK...		
29	FIT OIL SPRAY AND ALL OIL PIPES : (a) CHECK FIT AND ALIGNMENT OF ALL PIPES		
30	STAMP SERIAL NUMBERS		
31	TEST COMPLETE GEARBOX		
32	PAINT GEARBOX AND RUSTPROOF WHERE NECESSARY		

	Clutch Travel Ahd.	Clutch Travel Ast.	Clutch No. Ahd.	Clutch No. Ast.
R.H. UNIT				
L.H. UNIT				

REMARKS : (Anything Special to this Gear or Deviations from Standard Drawings must be Recorded Here.)

CONTROL COCK TESTED (DATE) :

PRESSURE RELIEF VALVES :

SET AT LBS □"

M.W.D. 48

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1946

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LLOYD'S REGISTER STAFF ASSOCIATION.

SESSION 1946-47.

DISCUSSION AND AUTHOR'S REPLIES
on
Mr. P. T. Brown's Paper

THE SURVEY OF MASS PRODUCTION

LLOYD'S REGISTER OF SHIPPING,
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The Author of this paper retains the right of subsequent publication, subject to the sanction of the Committee of Lloyd's Register. Any opinions expressed and statements made in this paper and in the subsequent discussion are those of the individuals.

DISCUSSION ON MR. P. T. BROWN'S PAPER.

MR. G. O. WATSON.

Neither in the title nor in the text does the author clearly indicate what type of survey he is dealing with, and this is most essential as the line of approach depends entirely on what the Surveyor is setting out to do. Survey of mass production, as affecting Lloyd's Register, can come under one of four headings :—

(1) For Classification purposes;

(2) On behalf of a purchaser. This happens frequently in connection with non-marine work, but may also arise where the Surveyor is "seeing the specification carried out";

(3) On behalf of a Government Department. This is similar to (2) but may involve more records and "returns," progress reports and greater attention to interchangeability, particularly in relation to war supplies where replacements are frequent and must be accomplished in the field with speed and despatch;

(4) As organisers of a firm's internal work's Inspection System. The Society has undertaken this function for the past ten years in the works of one of the leading manufacturers in the United Kingdom.

Incidentally, the author's derogatory remarks on the function of an Inspector will not bear critical examination. The term "Surveyor" is used mainly in connection with Civil Engineering and Shipbuilding, but in other industries, including Engineering, the term "Inspector" is preferred. All large firms of Consulting Engineers employ "Inspectors" for what the author describes as Surveying duties, and many large engineering works employ Inspectors for precisely similar functions. The Institute of Engineering Inspection caters for professional Inspectors of this type.

If parts are mass produced to such an extent that the Surveyor cannot reasonably be expected to make 100 per cent. inspection, but must rely to some extent on Work's Inspection, then he must judge the quality of the product by samples, and the author might well have explained the little-known art of scientific sampling in some detail. Sampling done scientifically can be 100 per cent. reliable if it is on a statistical and mathematical basis.

Scientific sampling was developed some twenty years ago by Dodge and Romig, and is now in regular use, and their tables, known as the Dodge-Romig Sampling Inspection Tables, were published early in 1941. An improved method, known as "Double Sampling Inspection," is now in use and published tables give the number of samples to be taken from various sizes of batch. It will be appreciated that in any sampling scheme a certain quantity of parts which depart from specification may get through, but this can be regulated to very small percentages. The first thing to determine before using the tables is the number of so-called defectives that can be permitted and the average quality of the product. To determine the latter it may be necessary in the first batch to examine 100 per cent. Without entering into technicalities we can by this method make the following assertions :—

(1) Without any knowledge of the product it is impossible even to approximate the quality of a batch from observations of a small sample.

(2) With knowledge of the general quality of the bulk product coupled with observation of a small sample it is possible to predict the batch quality with considerable accuracy.

(3) Without any knowledge other than by sampling inspection it is possible from observation of samples to judge whether the batch is of uniform quality.

(4) In the case of established uniformity of product it is possible from subsequent batches to say whether the uniformity of product is being maintained.

It is not possible in this discussion to enter into details of these methods, but anyone wishing to make use of this system will find further details in B.S.600 and in the "Symposium of Papers on Quality Control" in the Institution

of Mechanical Engineers' proceedings (Papers read on 17th December, 1943) and elsewhere.

Reference is made in the Paper to colour or other identification markings on Bar Steel. Where special steels are used it is important to investigate the firm's methods of storing and issuing material as arrangements are not always satisfactory, particularly under conditions of war-time expansion where stores were inadequate and material was kept in racks on the shop floor. There is very grave danger that a machinist, having spoilt a piece-part, may help himself to the wrong material, and in cases of suspicion or doubt a Brinell Test should be insisted on.

MR. R. MUNTON.

In classification work the checking of dimensions is not normally carried out by the Surveyor except for major strength items such as the thickness of shells, pitch and diameter of rivet holes, &c., and, where it is carried out, the measurement accuracy does not approach that for mass production.

In classification work my own attitude has always been that such items as jigs are the engine makers' particular concern.

Further, with regard to tolerances, provided the final assembly is satisfactory, these too I have considered to be outside my province.

Mr. Brown has the advantage that he has seen these aspects from the Society's and the mass production engineers' point of view, and I would much appreciate his ideas as to how far, if at all, the systems of checking given in the paper could, bearing in mind the extra work involved, be introduced in the Surveyors' ordinary work with value where mass production is not encountered but what might be termed "multi-production" is.

MR. S. ARCHER.

There is only one question I should like to ask, namely, to what extent were radiographic or magnetic methods of non-destructive testing employed in the mass production survey.

The Germans during the war carried out large scale torsional fatigue tests on crankshafts and found that faults which were only resolvable under the Magnoflux method of testing did not affect the fatigue strength of the shafts, the theory being that the flaws were, in fact, finely divided slag inclusions and not cracks.

MR. J. W. BELL.

An aspect of survey in a factory run on mass production lines is the personal approach of the Surveyor to the firm concerned. This point is touched upon by the author in his opening remarks, and, in my opinion, in so doing puts his finger on the hub of the matter.

In the writer's own experience the initial approach of the Surveyor in contacting a firm, and particularly that firm's Inspection Department, is of paramount importance. This is a great opportunity for the Surveyor to use his diplomacy to the full as it is usually found that the Inspection Staff consists of men or women who are highly skilled and have a pride in their work. As soon as they realise that the Society's Surveyor is not under the jurisdiction of the production department, and cannot be coerced in any way, they are only too pleased to work meticulously to the drawings and reject anything not within the prescribed limits.

MR. A. E. EVANS.

In mass production, component parts, cast or forged by various firms, despatched to others for machining and finishing, and eventually stored at different depots ready for use in building up the engine on its journey down the assembly line, must be correct for the finished product to function efficiently.

This is where the Surveyor by his experience of the functions of the numerous detailed parts and his wider outlook of the job would accept a component which perhaps an Inspector would "scrap" on account of an error of measurement of a thousandth part of an inch which was not vital to the efficient working of the engine.

Surveyors' duties are a check on the Works' inspection, and such vital measurements as crankshaft angles, sizes of journals and pins, alignment of connecting rods, &c., call for one hundred per cent. inspection in order to conform to the scheme of interchangeability, the importance of which cannot be too highly stressed.

In the earlier days of building Paxman Ricardo 500 B.H.P. engines, for example, it was unthinkable to run a crankshaft which had not been bedded in to its bearings by the monotonous and long process of trial and error, yet with precision turning, grinding and honing of journals and pins, precision boring of bearings, these parts are assembled with the designed oil clearance with successful results.

The co-operation of manufacturers and of technical specialists resulting in the publications of the British Standard Specifications show the desire of leading authorities for standardisation.

Lack of standardised parts of an engine aboard ship in a distant port has caused much anxiety for the Chief Engineer, who has to find ways and means to keep the job going, whereas a standard component part at hand would smooth out all difficulties and keep costs and delays for the Shipowner to a minimum.

MR. W. E. PACKMAN.

If the Society continues to undertake Survey (or Inspection) of mass produced products, the question of "approval inspection" must eventually arise, as it will be practically impossible to follow the Society's Rules to "inspect throughout." I would respectfully suggest that now is the time for this aspect of the Society's activities to be fully investigated, so that definite requirements with which firms granted approval would have to comply, can be formulated. The actual degree of inspection required to be carried out by the Society's Surveyor should also be fully determined before the commencement of the contract in order to maintain uniformity of inspection.

Under the heading "Inspection Scrap"—which I suggest should have been headed "Inspection Rejects"—Mr. Brown refers to the "inquests" on rejected parts. This point raises the question of salvaging processes, such as fescolising, chromium-plating, metal-spraying, welding, &c., of machined parts, impregnation of pourous castings, &c., &c. I feel sure that all Surveyors would welcome some guidance on these processes, that is, processes which the Society will approve, and where applicable.

Under the heading "Conclusion" Mr. Brown states "and the adaptation of Works' system to meet the Society's requirements." This, in some cases, is no easy matter, especially if left to the particular Surveyor on the job, at a Works where systematic arrangements are absent. I have had some experience of this difficulty myself. It appears to me that under the "Summary of Things," Appendix 1, the headings for each column should be altered to read: "To Know—Surveyor" "To Do—Society." By Society I mean the administrative section of Lloyd's Register.

MR. L. C. DAVIS.

One inherent penalty of mass production is "Inspection Scrap." The price which the system demands is the rejection of serviceable articles whose only fault is that if retained they would have to be used in conjunction with other parts having complementary dimensional variations. On occasion such discarding may mean the sacrifice of many days' valuable work for blemish which, while vital in mass production, would not be discernible in free hand work, and the most effective measure in minimising such tragic wastefulness is an intelligent resource to what the author aptly describes as "inquests."

We can respect America's skilful adaptation of unskilled labour without envying her. Great Britain is a small country whose industrial reputation has been built up by its craftsmen, and British craftsmen have been welcomed in the four corners of the earth as pioneers of Industry.

MR. T. D. SCOTT.

Mr. Brown makes no direct mention of the magic words "Interchangeability of Parts" in mass production, although the point is undoubtedly covered by "Summary of Things to Know," No. 3. This, in my opinion, is one of the main aims in mass production, and cannot be over-emphasised, and complete interchangeability can only be brought about by adhering strictly to the dimensional limits as set forth on the appropriate drawing. This aspect is not always apparent to those not in direct contact with this type of work, or to the machinist, who

is apt to resent having his work rejected by the Surveyor because of a few tenths of a "thou," as also does "Progress," who is probably behind in his deliveries anyway. Those few tenths of a "thou," however, may well mean considerable delay in the erecting shop, or anxiety on a lee shore, were the faulty component being fitted as a spare part.

The remarks on identification are most important, and here again the full co-operation of "Inspection" is necessary, if only in order to keep track of the units of a batch of, say, crankshafts to one Lloyd's Test Number. In this instance, each shaft is given a works serial number in addition to the Lloyd's batch number, and it is the job of the floor Inspector to transfer these numbers during, or between, operations.

It might well be that the "multiple engine" idea will develop and become the Motorship of the future, leading to mass production of a standardised engine, as envisaged by several oil engine manufacturers. Should this come to pass it will become a practical necessity to adopt Mr. Brown's suggestion of some system of Approved Inspection under the general supervision of the Society's Surveyors on the lines of the highly successful A.I.D. organisation.

MESSRS. G. ANDERSON AND T. W. BUSHELL.

referring in a letter to their experience in the Birmingham district during the war state it has been their experience that the main difficulty in any Works Inspection Department is the question of remuneration, and they believe most firms find that any system of piece rate or bonus tends to defeat the object for which the Inspection Department was instituted. In spite of this, most firms are compelled to use such a system with the result that in many cases there are defects in it which can have serious results. Some firms have endeavoured to overcome this by instituting a system by which the Inspectors are paid some extra for all defective material discovered. This again raises a difficulty in the possibility of good material being rejected unless a further "deciding" inspection is in operation. They feel that one solution would be to have the whole of the Inspection personnel on a "Staff" basis, in spite of attendant difficulties, and this will probably be the ultimate solution. The psychological effects of such a decision could be very considerable, as such an arrangement would tend to make the Inspection Department "part of the firm."

MR. H. F. MANSFIELD.

With reference to Appendix 1, the first "Things to do" in which it is stated "Explain scope of Surveyors' duties and the Society's requirements to the Management and invite its co-operation" raises a point on which a great deal may be said. If the Works are commencing to manufacture on a mass production basis the matter is comparatively easy, as one is then in at the start of the job. The case is rather different when a Works commences to change over to mass production. The firm will already have a well tried and proved organisation for producing their machines to individual orders, but it will be found that owing to increasing orders this system is not flexible enough. Therefore it is decided to manufacture catalogue types of machines in large batches and allocate the units to the various orders.

When a certain order is to be built under survey it means that a certain number of units are "frozen" and cannot be switched as required. This rather defeats the object of the system, as no matter what high priority job comes along those particular units cannot be touched.

One method of overcoming the above difficulties is for the Manufacturer to decide to have all components for certain ranges of machines made under survey and to use them in the standard as well as units built under survey.

MR. F. G. BROOKE SMITH.

Mr. Brown asks us to assume that a firm which is mass producing plant or machinery of any description does not include properly organised planning and inspection departments. If such should prove the case it is easy to imagine that a state of chaos would prevail in a very short time, despite all the efforts of one or more of the Society's Surveyors.

Coming to the various Appendices and dealing with No. 1 (Nos. 2 and 3 do not convey anything tangible to me except the fact that they are

probably typical examples of processing cards in use at a mass production works), the author says the Surveyor should know the construction and operation of the machinery or plant being built under survey, even though only concerned with a detail. During the late war the writer personally passed out many thousands of an engine detail without being able to ascertain (*a*) what is was for, and (*b*) why the materials were used until, when visiting a landing craft at the end of hostilities, a number of these self same parts were observed.

In the course of official duties the writer frequently visits works producing on mass lines, and can assure the author that in general the control and organisation is such that there is no necessity for any adaptation of works' systems to meet the Society's requirements.

In conclusion, I would like to ask Mr. Brown that now the Society is rapidly coming back to its normal peace-time activities where will the average, if any, Surveyor be called upon to exercise his talents in a works mass producing under the conditions set out in the paper? It is difficult to visualise, for the present at any rate, main engines, auxiliaries and boilers being mass produced on the track system.

MR. A. T. ROBERTSON.

In connection with the handling of materials, more particularly of forgings, I wonder if the author's views will coincide with mine. I believe that in the mass production of drop stampings a good deal of wasted effort and useless wear and tear of machinery can be and is caused by the articles, such as crankshafts and connecting rods, being piled carelessly and haphazardly one on top of another as they are stamped, and so becoming bent or twisted out of alignment. This, I think, is a matter for the Surveyor's periodic attention.

There is one problem that I should like to have Mr. Brown's views upon with reference to the mass production of components intended for replacements. How should one deal with the question of Rectification and Modification of Limits (Tolerances) in order to reduce or eliminate the scrapping of parts with minor faults?

MR. H. V. CAMPBELL.

On page 3 attention is drawn to the fact that acceptance of a quantity of articles on a percentage inspection does not limit the responsibility to those personally checked. Surely responsibility is limited to the degree of inspection stated in the Certificate covering a particular batch, e.g., a certificate issued for a batch of 10,000 special bolts would probably state that 10 per cent. of these were inspected. By inference the remainder are considered satisfactory. If this insistance on absolute responsibility were stressed too much, a somewhat sensitive and inexperienced Surveyor would find himself tied up with one job to the neglect of a score of others.

On page 4 this view seems to be accepted by the author, as he states, in reference to tests of mass produced items, that he (the Surveyor) "cannot personally watch every test through."

REPLIES.

To Mr. Watson.

Mr. Watson has much experience of Works employing mass production methods, and the author is gratified at his interest in this paper, to which the information on sampling inspection and the illustrations of fallacious sampling are appropriate additions which should be of considerable interest to most of our members. It is complained the type of survey has not been defined, but as the author clearly indicates he deals only with the principles and whether the category is 1, 2 or 3, as designated by Mr. Watson, these are the same although admittedly the special requirements of the client will affect the detail. There is no fundamental difference between the requirements for categories 1, 2 or 3. No matter who is responsible for the payment of the fees they come from the purchaser's pocket, and it is the purchaser's interests which have to be served. Category 4 is not within the scope of the paper.

The author, having a very high opinion of the character, knowledge, capacity and ability of many mechanical engineers graded as Inspectors, regrets Mr. Watson should consider his remarks derogatory to the function of the Inspector, and suggests the paragraph be re-read.

The fundamental point is that the Society, and therefore the Surveyor, is taking responsibility for the plant or machinery concerned for its ultimate service function. The Surveyor will, or should, understand these service conditions (as also a Consulting Engineer's "Inspector") but it is not incumbent on a manufacturer that his Inspectors should have such knowledge.

The author thanks Mr. Watson for his endorsement of the care necessary in the marking, storing and issue of materials. The subject is of primary importance, and nothing less than the four requirements given under the heading "Processing" can be considered satisfactory. Receipt, storage and issue of materials must be well organised if factory production is to be efficient and reliable.

To Mr. Munton.

The answer to Mr. Munton lies in the Engineering—as apart from the Commercial—virtue attainable by Mass Production, viz., Interchangeability. In the case of Classification—to take an example from a field with which Mr. Munton is particularly familiar—refrigerating machines might well be mass produced.

Manufacturing process—questions of jigs and tools—is definitely of interest to the Surveyor Actually he will not intervene unless something goes wrong, but should his valuable time be wasted in inspecting material unworthy of presentation he should enquire into the cause of the faults and give his views to the manufacturer even should this involve criticism of tools or methods. My experience is that when a firm is convinced that the Surveyor has a sincere interest in the production of a good article, criticism will be accepted as co-operation and will not be resented.

With regard to multi- or bulk-production, the methods of control indicated in the paper will give optimum results, and, moreover, entail much less work than would obtain by dealing with the job as in free-hand construction.

To Mr. Archer.

In reply to Mr. Archer, magnetic crack detection, and also X-ray examination, are much employed in mass production, but a word of caution is necessary in regard to the application of these non-destructive tests which are extremely sensitive. Correct interpretation of defects revealed is only possible after considerable experience, and the author can recall cases where magnetic crack detection had to be abandoned in the interests of production.

On one occasion a serious epidemic of grinding cracks in gudgeon pins was revealed by a detector. Samples were deeply etched and a "foot rule" established as to the extent of defect revealed which might be tolerated. The next step was to test defective pins in a lower powered magnetic detector. This was less revealing. Any pins appearing clear on this test were accepted, and a selected number which exhibited defects were fitted to engines and tried out on the test benches and, if memory serves me correctly, only one flaked in way of cracks. It was decided that close and careful visual examination was sufficient.

From the above it must not be assumed these tests have no place in practical inspection. Far from it. They are most valuable but require intelligent application and experience in interpretation.

To Mr. Bell.

Mr. Bell's remarks about the control of Inspection by Production Management are dealt with in the reply to Messrs. Anderson and Bushell, and the points there made cannot be too strongly emphasized.

To Mr. Evans.

Mr. Evans' information concerning experience with Diesel engines mass produced for Tank Landing Craft will be of interest to many colleagues. He mentions the advantages of adherence to dimensions and the interchangeability of parts only obtainable under mass production methods.

To Mr. Packman.

When one considers the wide field covered by the Society's surveying services it will be realised a general approval of Salvaging Processes is not possible. The general question of the utility of various salvaging processes might be dealt with in a circular describing them and giving examples of their limits and possibilities.

The author appreciates Mr. Packman's difficulty where there is no organisation and no system to adapt. The logical answer that if there is nothing to adapt one only has to apply the Society's requirements will not be easy to execute. The suggested amendment to Appendix 1 does not find acceptance. The Society is not represented by an Inspector but by a Surveyor, and it is his duty and privilege to exercise authority in the Works under his control.

To Mr. L. C. Davis.

That Mr. Davis' kindly disposition should be outraged by the scrapping of parts for dimensional errors is understood, but interchangeability is an essential and there need be no solicitude for the manufacturer.

To Mr. T. D. Scott.

Mr. T. D. Scott has had a good experience in the erection of mass produced engines, and his contribution is most welcome.

To Messrs. Anderson and Bushell.

Messrs. Anderson and Bushell raise a point which was of much concern during the war. There is no doubt of the evil which can arise from the bonus system, and when the inspectorate is included things become very difficult. The remedy is simple. The inspectorate must be *salaried staff* and well paid, and the Chief Inspector responsible to the Managing Director only. Even the General Manager should have no authority over him. It may not be inappropriate to here record that the Chief Inspector of Messrs. Ford was appointed by Henry Ford himself and was directly responsible to him.

To Mr. Mansfield.

The Society already has precedents which cover points raised by Mr. Mansfield. If a manufacturer places the whole of a certain production under survey, arrangements could be made by which only a nominal fee would be incurred if the survey is terminated before a certain stage is reached. The crucial point is materials. If these are tested the rest is easy. In this connection the advantages from specifying the Society's survey for all important materials and forgings are being increasingly recognised by manufacturers.

To Mr. Brooke Smith.

It is not understood why Mr. Brooke Smith considers he is "asked to assume that a firm which is mass producing plant or machinery of any description does not include organised planning and inspection departments." The author makes no such request either directly or by inference. On the contrary he states on page 1 "An efficient Inspection Department is an essential feature in the organisation of Works producing on mass lines." Further, he advocates taking advantage of the facilities afforded by this department and recommends co-operation with it. In fact, the conclusion summarises the survey as "close co-operation with all the departments and adaptation of their systems to meet the Society's Requirements.

The forms shown in Appendices 2 and 3 represent the ideal method of ensuring full control and accurate inspection. All these forms, except that applicable to pistons, were drawn up in this office and were eagerly adopted by manufacturers concerned with outstandingly good results. They are "Inspection" and not "sequence of operation" cards. Mr. Smith refers to certain details about the function of which he did not enquire. It was no serious omission of Mr. Smith to omit enquiring about the functions of the thousands of castings for butterfly nuts (T.P.354) he inspected. Had he been responsible for the machining of them, however, it would have been pertinent to know the function of the narrow groove and why the countersink was dimensioned.

Mr. Brooke Smith is entirely wrong in attempting an assurance that any Works' system meets the Society's requirements. This could only happen under a system of Approved Inspection, and even then the Society would exercise overall

control. It cannot be assumed the whole output of a mass producing firm would be to the Society's Survey, and for Surveyors to break into the rhythm of production or inspection with the Society's Rule Requirements would impede the normal flow.

Regarding the query in Mr. Brooke Smith's penultimate paragraph, the Society is already surveying main engines for peaceful purposes building by mass methods, and the author visualises a great extension of the idea to auxiliary engines and specialities. We have also to consider the non-marine field, in which the Society's activities are ever increasing.

To Mr. A. T. Robertson.

Mr. A. T. Robertson raises a practical point of importance in the matter of piling forgings. It is not only when hot from the press that these items get distorted; it will happen when cold unless carefully stacked. Forgings and castings should be stacked so that the weight is evenly distributed over the widest base, and stacks should not impose excessive weight on the lowest layer.

In reply to Mr. Robertson's query. The Surveyor will know the maximum limit to which drawing tolerances may be stretched, and to this figure he should work. In the matter of major rectification the Surveyor should satisfy himself that a sound and workmanlike job can be made, and then, depending on circumstances of contract, either submit the case to the London Office or personally obtain the customer's agreement.

To Mr. Campbell.

Mr. Campbell has raised a point which the author is glad to clarify, with the example quoted. If 10,000 special bolts are ordered to the Society's survey, the certificate will be for 10,000 bolts, and the responsibility is therefore for 10,000 bolts, regardless of the fact that the Surveyor, by reason of his experience and knowledge of the Works, is satisfied that a thorough inspection of 1,000 bolts is sufficient to give him the necessary confidence to accept the whole quantity. Experience is necessary to gain this confidence, but for the benefit of the sensitive and very conscientious Surveyor it must be added that most purchasers are reasonable and will not object if they receive, say, 1 per cent. scrap.

Mr. Campbell's reference to page 4 is not appropriate, as the remarks there concern final testing of assemblies, e.g., bench tests on I.C. Engines, &c.

CONCLUSION.

In conclusion, the author feels this discussion has aroused interest in a field of survey with which the Society is becoming increasingly concerned. Many of our colleagues who were engaged during the war in work of this nature developed great enthusiasm, and have informed the author of the profitable experience gained by the necessary closer contact with production. They all found how control could be effectively maintained by carefully kept records, and much ingenuity was shown by them in devising or adapting such.

Although the possibilities of mass production methods do not appear to have been explored in Marine Engineering, there exists a wide scope for its application in both new construction and repairs. The adoption of multi-engine propulsion would offer the opportunity of using standard engines produced in large quantities with their many attendant advantages.

In connection with Auxiliary Machinery, mass methods of production and repair offer considerable opportunity to increase efficiency and reduce costs. Rationalisation of production is badly needed, and the time is long overdue for shipowners, marine engineers and manufacturers of auxiliaries to get together and decide on standard types and sizes. With fewer types and sizes, manufacturers, by confining their activities to the production of an agreed and limited range of specialities, would effect tremendous savings.

Reconditioning would also be on mass lines and result in re-issue of a job equal to new. In this connection it has to be recorded that the Society's Surveyors during the war supervised the overhaul on these lines of 1,200 500 B.H.P. Paxman Engines ex Tank Landing Craft, including full power bench test to original requirements. Incidentally the Surveyors were able to do this in their stride as a side line to a full-time job.

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TEMPORARY HULL REPAIRS TO THE TANKER "MARKAY."

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TEMPORARY HULL REPAIRS TO THE TANKER "MARKAY."

Part 1.—GENERAL.

THIS 500-foot tanker, after sustaining damage to the extent of having about 200 feet of the forward bottom plating and internal structure torn off, by running ashore at the Island of Skye, proceeded under her own power in winter to Swansea and, after temporary repairs which still left about 125 feet missing, crossed the Atlantic Ocean to the United States of America for complete permanent repairs. It is considered, therefore, that some details of the nature and extent of these temporary repairs might be of interest.

The principal dimensions of the "Markay" are:—

Length overall	...	520 feet
Length, B.P.	...	500 „
Beam, moulded	...	68 „
Depth, moulded	...	37 „

The hull was of part-welded and part-riveted construction, the shell seams from the keel to the upper turn of the bilge being welded and those above riveted; all deck plating seams were riveted. Shell and deck plating butts throughout the ship were welded. Bottom longitudinals were welded to the shell, side and deck longitudinals riveted. The two oil-tight longitudinal bulkheads and the oil-tight transverse bulkheads were of the Bethlehem-Frear corrugated type and of all-welded construction. The vessel was classed, for the carriage of petroleum in bulk, by Lloyd's Register of Shipping and the American Bureau.

It was known from divers' reports before the vessel arrived at Swansea that the damage was fairly extensive, and due precautions against further damage were therefore taken at dry-docking. This operation occupied about ten days, during which period the vessel was gradually let down on keel blocks aft and on specially prepared shores forward.

Examination then showed that about 200 feet of the bottom and side shell was torn off, the damage extending from the stem to near the aft end of No. 4 cargo tank and to an average height of about 11 feet above the keel; on the port side at the middle of No. 3 tank the side shell was torn off to a height of about 15 feet above the keel. The lower parts of all transverse and longitudinal bulkheads were torn off to about the same height; the lower parts of the centre line bulkhead in the fore deep tank, the forward cofferdam and No. 1 cargo tank were similarly torn off. The floors in the fore peak tank and the centre-line girder in Nos. 2, 3 and 4 cargo tanks were missing. The bottom shell of No. 4 starboard and No. 5 port cargo tanks was buckled and pierced (Figs. 1, 2 and 3).

It is estimated that the weight of steel torn off at the time of grounding, added to what had to be removed prior to making any temporary repairs, was about 500 tons.

Above the mean height of 11 feet, apart from the deep notch in the port side, the shell was practically undamaged, although shell longitudinals, side shell webs and bulkheads were badly buckled for a few feet higher. The deck, however, sustained no damage and no failure of the welds in the butts of deck or remaining shell plating was found.

Consideration was at first given to permanent repairs, but, due mainly to shortage of labour and for military reasons, the practicability of only temporary repairs had to be investigated, and it was finally decided that, to make the damaged vessel suitable for a voyage in ballast across the Atlantic to the U.S.A., these would be as follow:—

1. The fore peak and fore deep tank, extending for a length of about 75 feet, to be fitted with a steel-plated vee-shaped temporary bottom to restore some of the lost buoyancy forward.

2. Five longitudinal girders to be fitted to restore some of the lost material; one on the line of the side shell on each side of the ship, one on the line of each of the two longitudinal bulkheads and one on the centre line of the ship, all five being attached at their after ends to the existing undamaged structure and at their forwards ends to the new temporary bottom forward.

3. The existing side shell and longitudinal bulkheads with the existing web frames and stiffeners on them to be plated down where necessary, and attached to their respective girders.

4. The transverse bulkheads to be fitted with brackets to support the centre line girder.

5. All five girders to be cross-tied by channels at intervals of approximately 12 feet.

6. No. 4 starboard cargo tank and No. 5 port to be made water-tight by plating over the buckled and pierced shell and by cement filling.

As the damaged part of the ship extended to within L/10 forward of amidships the amount of material to be built in as a temporary repair to take the place of the missing or damaged structure was a matter of some importance. Based on approximate calculation a proposal was put forward to make the total cross-sectional area of the five girders not less than 25 per cent. of the cross-sectional area of material torn off, taking the damage as extending to 11 feet above the keel. This proposal was approved by both Classification Societies and proved acceptable to the Underwriters and other parties concerned. It was also agreed that the vessel should make the voyage to the U.S.A. in ballast at a draught of 18 feet forward and 22 feet aft.

The sectional area lost was about 1,340 square inches and included bottom and side shell plating and longitudinals, the centre line girder and lower part of the longitudinal bulkheads. The area actually restored was about 336 square inches. The girders on the centre line and on the line of the longitudinal bulkheads were each built up from a $48'' \times \frac{1}{2}''$ web plate, four 12″ channels and a $24'' \times 1''$ bottom rider plate. The shell girders each consisted of a $30'' \times \frac{3}{4}''$ plate with a 12″ face channel and an $8'' \times 6''$ angle connection to the shell. (Figs. 8 and 9.)

To avoid abrupt change of area at the junction with the existing shell at their after ends, the girders on the centre line and longitudinal bulkheads were reinforced with $48'' \times 1''$ rider plates for about 48 feet. In addition, the port longitudinal girder and that on the centre line were attached to the shell plating by large brackets 1 inch thick, 6 feet wide and about 20 feet long. Large brackets were also fitted at the junction of the existing shell with the shell girders. Other suitable means of making the aft end attachments of the starboard side of the centre line girder and of the girder on the starboard longitudinal bulkhead were developed during the course of the repairs and were as shown in the sketches. (Figs. 8 and 9.)

To reduce the time of construction and occupation of the dry-dock as much as possible it was decided that the girders on the centre line and on the longitudinal bulkheads should be prefabricated at any available steel constructor's yard or shipyard. Actually eleven lengths of girder were made in Port Glasgow and built into the ship by the repairers at Swansea. End lengths which were to be attached to the ship and which it was considered would have to be adjusted in length in the dry-dock were made and fitted in place by the repairers. (Figs. 6, 7 and 8.)

The plating of the vee-shaped temporary bottom forward was $\frac{1}{2}''$ thick and supported by $\frac{1}{2}''$ thick floors in the fore peak and by 15″ channels and intercostal girders in the fore deep tank. (Fig. 5.)

At the same time it was decided to fit docking stools to facilitate dry-docking for permanent repairs in the U.S.A. Three of these were fitted, one on the centre line at the fore deep tank and one port and starboard on the longitudinal bulkhead at the forward and after side of the transverse bulkhead between No. 2 and No. 3

tanks. These stools consisted of a vertical plate attached to the remaining centre line bulkhead or longitudinal bulkhead, a base plate and suitable stiffening. (Figs. 6, 7 and 8.)

As finally arranged at the ship the temporary forward bottom was 6 feet above the base at the centre line and 10 feet at the vessel's sides. The new girder, about 125 feet long, on the centre line, inclined up from the keel at the aft end of No. 4 tank to the new bottom forward and those on the longitudinal bulkheads inclined up from the bottom plating at the aft end of No. 4 tank to the new bottom. Those on the shell were 7 feet above the base line aft and rose up to the new bottom. The new longitudinal material was thus added in an effective, practicable position where it was likely to be most required near the bottom of the ship at the aft end of No. 4 tank. (Figs. 4–9.)

On the voyage from Skye to Swansea compressed air had been used in many of the damaged compartments to keep the ship afloat; and the question of using compressed air on the voyage to the U.S.A. was considered. Finally it was decided to have compressed air in No. 3 tank only and the transverse bulkheads at the forward and after ends of this tank were plated down for a distance considered sufficient to prevent loss of pressure when a wave hollow came in way of this tank.

To keep the air in other damaged tanks at atmospheric pressure the ullage plugs (about 9 inches diameter) in the tank hatchway lids were to be left open during the voyage but the lids themselves were to be closed and secured. With these arrangements air in the tank could escape as the water in the tank rose due to the passage of a wave crest, and at the same time the tank could be quickly closed and thus provide buoyancy in an emergency, such as the new bottom forward becoming badly damaged and pierced.

Suctions were also fitted to the fore peak, fore deep, No. 4 cargo tank starboard and No. 5 cargo tank port to deal with any leakage that might develop during the voyage.

Thus, when the ship left Swansea for the ocean voyage, most of the buoyancy lost by damage to the fore peak, the fore deep, No. 4 starboard and No. 5 port cargo tanks had been replaced and some of the strength lost in torn-off bottom and side shell and longitudinal bulkheads was replaced by the five girders.

With these temporary repairs, which still left about 125 feet open to the sea, the "Markay" crossed the Atlantic during May, 1944, without incident, and was subsequently dry-docked in the U.S.A. where permanent repairs were effected. The draughts at departure were 22 feet aft and 18 feet forward when the vessel was loaded with water ballast in cargo tanks Nos. 5 to 9, oil fuel, fresh water and stores.

Part 2.—STRENGTH CALCULATIONS.

TO ascertain that the reinforcement proposed to be fitted, as described in Part 1, would maintain the maximum stresses within reasonably safe limits, a series of strength calculations was made. This was carried out by the standard method of ship on a wave of the same length as the ship, and involved drawing weight, buoyancy, load, shearing force and bending moment curves. The pressure of compressed air in No. 3 tank complicated the calculations to a certain extent, but full account of it was made.

Weight Curve.

For the weight curve the well-known Biles weight curve was used as a basis and modified as considered necessary to suit the tanker form. This basis included only the weight of the steel and wood and outfit. Corrections were then made for steel structure, cargo pipe lines, etc., lost, for new structure (about 200 tons) added and for ballast, stores, etc., to be carried during the voyage. Allowance was also made for the machinery which was added as an isolated weight at the aft end. Most of these weights

and the position of their centres of gravity were estimated and were proved to be fairly correct when the vessel floated off the blocks at the estimated draughts. (Figs. 10 and 11.)

Moduli of Sections.

Modulus of section was calculated for undamaged ship, damaged ship (assuming damage extending to 11 feet above the base) and reinforced ship. The material included in each calculation is shown in Figs. 12a–12e. The girders being directly connected to the shell plating at their after ends, the large brackets referred to in Part 1 were also included in the calculation of Modulus.

Buoyancy Conditions.

For reasons given later in this paper, it was decided that compressed air for buoyancy purposes was to be used only in No. 3 tank (port, centre and starboard). Two conditions were then investigated: "A" with no initial compression and "B" with initial compression in this tank. To obtain condition "A" the lids of all tanks would require to be left open while the ship was being floated off the blocks and ballasted to bring her to draught of 18 feet forward and 22 feet aft. The lids on No. 3 tank being then closed, the pressure in the tank would be atmospheric, the gauge pressure would be zero, the water level inside the tank would be the same as that outside, and the buoyancy effect of the air would be zero. To obtain condition "B" the lids in No. 3 tank would require to be closed before water was run into the dock. As the water rose in the dock the tank would, after a time, become sealed off at the open bottom and thereafter the air in the tanks would become compressed. Ballast would then require to be added to bring the ship to the draughts of 18 feet forward and 22 feet aft. At this stage the air in the tank would be at a pressure greater than atmospheric, the gauge pressure would be positive, the water level inside would be higher than that outside and the air would have a buoyancy effect. It was calculated by Boyle's Law that this initial pressure would be about 2.7 lb. per square inch, with an equivalent buoyancy of about 410 tons. Because of this buoyancy increase an equal increase in ballast would be required for condition "B" as compared with condition "A". Condition "B" could also be attained by placing all the required ballast on board before the dock was flooded. When the ship floated off the blocks she would be at the required draught and the pressure in No. 3 tank would be as above.

The ship being in either condition "A" or "B" the passage of wave hollows and crests along the ship causes corresponding momentary decreases and increases in pressure of the air in No. 3 tank; the buoyancy effect changes, in condition "A," from zero to a negative or positive quantity, in condition "B," from a positive quantity to a smaller or greater positive quantity. If in condition "A" a large wave hollow passed No. 3 tank and opened it to the atmosphere the pressure of the air in this tank would become atmospheric during the passage of the wave hollow, but if the ship were then to sail into smooth water it would be found that the air in No. 3 tank would be at a pressure greater than atmospheric and that the forward draught had decreased, i.e., the initial conditions would be changed. In condition "B" a large hollow passing No. 3 tank and opening it to the atmosphere would reduce the pressure of the air in the tank to atmospheric and subsequent compression as the ship moved into smooth water would only restore the initial conditions. Condition "B" could be regarded as a recurring condition.

Condition "A".—In "Sagging A1" position the vessel is on the standard wave 500 feet long and 25 feet from hollow to crest, the hollow being amidships; and it has been assumed that No. 3 tank has not been opened to the atmosphere by the passage of an earlier wave hollow. The relative position of vessel and wave are as in Fig. 13a. In "Hogging A1" position the wave is assumed to have passed along the ship until the crest arrives at amidships as in Fig. 13b.

In "Sagging A2" the wave is assumed to have passed along the ship and opened up No. 3 tank to the atmosphere when the wave hollow was at No. 3 tank. As the wave passes further aft the air in No. 3 tank becomes compressed to a pressure greater than atmospheric. The ship is

now in the hollow of the wave, but the condition is not the same as in "Sagging A1". See Fig. 13c. As the difference in stresses between "Sagging A1" and "Sagging A2" were small, no further investigation was made into condition "A".

Condition "B".—In "Sagging B" and "Hogging B" positions the vessel is in a hollow and wave crest respectively. The question of No. 3 tank being opened, or not being opened, to the sea by the passage of an earlier wave hollow was not required to be investigated because this event left the initial condition unaltered. See Fig. 13d and 13e.

Buoyancy, load, shearing force and bending moment curves were drawn for all these conditions and positions, and from these and the section moduli, stresses were calculated which were found to be as set out in the Table of Stresses below. Two sets of curves are reproduced—one for condition "A", "Sagging A1", and the other for condition "B", "Hogging B".

TABLE OF STRESSES in tons per square inch at the keel or lowest point of new centre girder.

(T = Tension. C = Compression.)

	STATION.		
	Aft end of No. 4 Tank.	Aft end of No. 3 Tank.	Middle of No. 3 Tank.
Condition A.			
Sagging A1	3·0 T	4·4 T	4·9 T
Hogging A1	4·0 C	4·2 C	4·0 C
Sagging A2	2·8 T	3·6 T	3·8 T
Condition B.			
Sagging B	3·7 T	4·7 T	5·0 T
Hogging B	3·3 C	3·8 C	3·8 C

From this it is seen that none of these stresses is dangerously high and that the difference between condition "A" and condition "B" is small.

In deciding how many tanks were to have compressed air the following sequence of events was considered possible if all tanks open to the sea at the open bottom had the lids down and the ullage plugs shut:—

(*a*) On the passage of a sufficiently large wave hollow all these tanks could be opened to the atmosphere via the open bottom. (Fig. 14b.)

(*b*) On the passage of the succeeding wave crest the air in these tanks would become compressed, and if at the same time the ship pitched into the crest the buoyancy effect due to the compressed air plus that of the water-tight fore peak and fore deep tank would set up a large bending moment in the region of the aft end of No. 4 tank, giving rise to stresses outside a safe limit; approximate calculations gave a stress of 14 tons per square inch tensile at the keel at the aft end of No. 4 tank. The compressed air pressure would also have been very high. (Fig. 14c.)

(*c*) If the ship did not pitch into the crest the bow might rise high out of the water and make the navigation of the ship extremely difficult.

(*d*) If the condition "C" did arise it would only be possible to bring the ship back to her original draught forward by filling the fore peak and fore deep tanks, all other intact ballast tanks being situated too far aft to have much effect in trimming the ship by the head. But to fill the fore peak and fore deep tanks seemed to defeat the object in making them water-tight by fitting the new temporary bottom in the first place. For all these reasons, then, it was decided to have compressed air in No. 3 tank only, and, as already stated in Part 1, that was the only tank under compression when the ship sailed.

Some assumptions were necessarily made in the above calculations. The main one was that although the lower edges of side shell and longitudinal bulkheads were not supported and

united by a bottom shell, yet the arrangement of girders fitted on their lower edges and the cross-tying channel bars was such as would make the general girder theory of ship strength applicable to this ship. With the ship in a sagging condition and the bottom reinforcing members in tension, this assumption is probably fully justified; in the hogging position the absence of bottom plating might allow the lower edges of the side shell and longitudinal bulkheads to yield laterally in a way not taken into account in the girder theory. However, experiments in H.M.S. "Wolf" led to the inference that bending moments which come upon a ship at sea are less than those assumed in the standard conditions.

In conclusion, it should be added that these repairs were carried out at Palmer's Drydock, Swansea, by the Prince of Wales Drydock Co., Swansea, Ltd. The general design, strength calculation, preparation of detailed working plans, arrangements for prefabrication, supervision of the work and issue of an Interim Certificate for the voyage were undertaken by the Surveyors to Lloyd's Register of Shipping.

The writer wishes to express his thanks to the Owners of the vessel, Messrs. The Keystone Tankship Corporation of Philadelphia, for permission to write this paper.

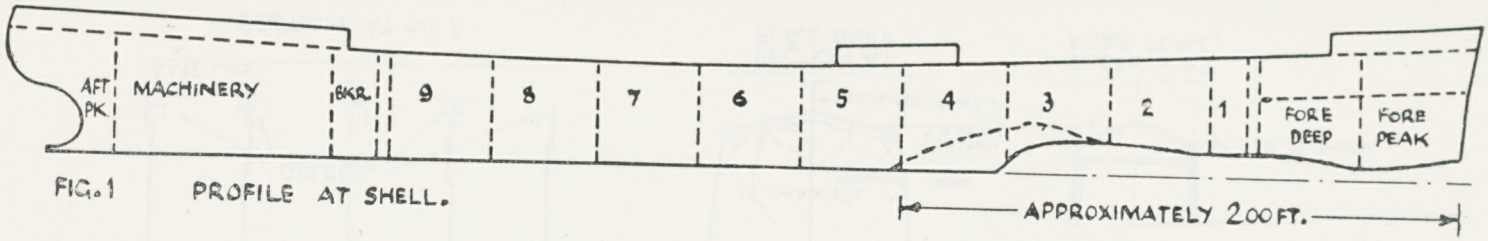


FIG. 1 PROFILE AT SHELL.

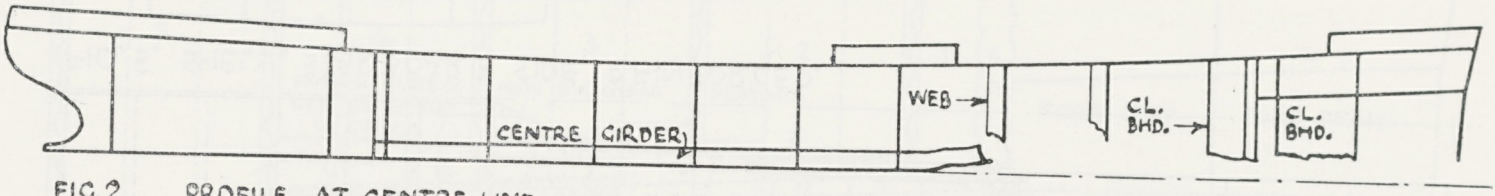


FIG. 2 PROFILE AT CENTRE LINE

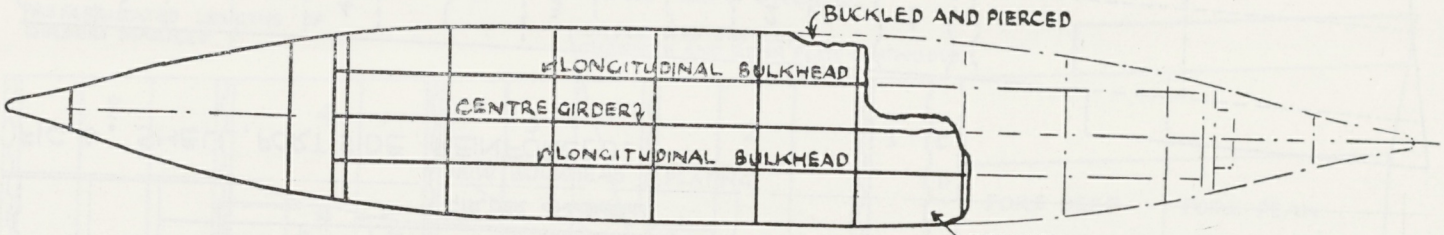
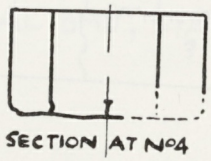
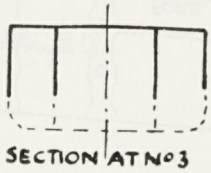


FIG. 3 PLAN OF BOTTOM.





FIGURES SHOWING EXTENT OF DAMAGE.

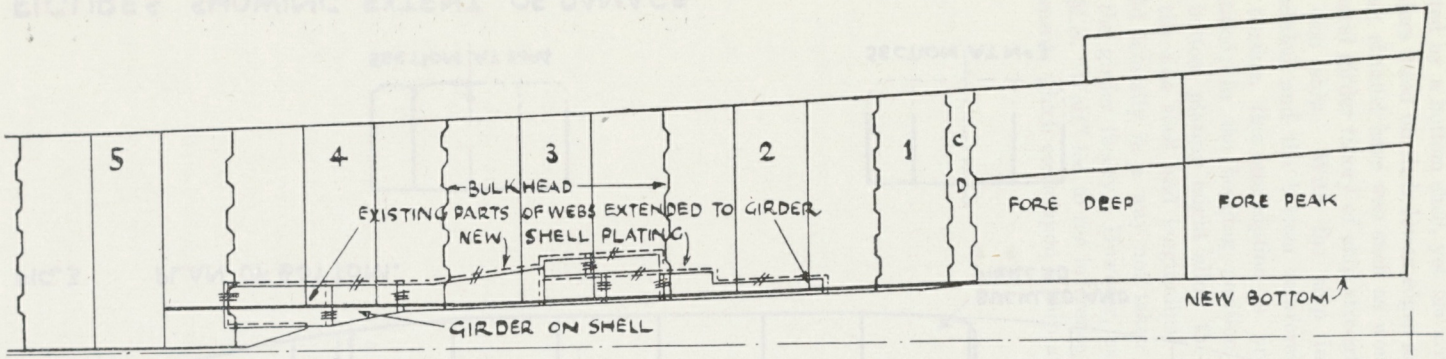


FIG. 4. SHELL, PORT SIDE, REINFORCED.

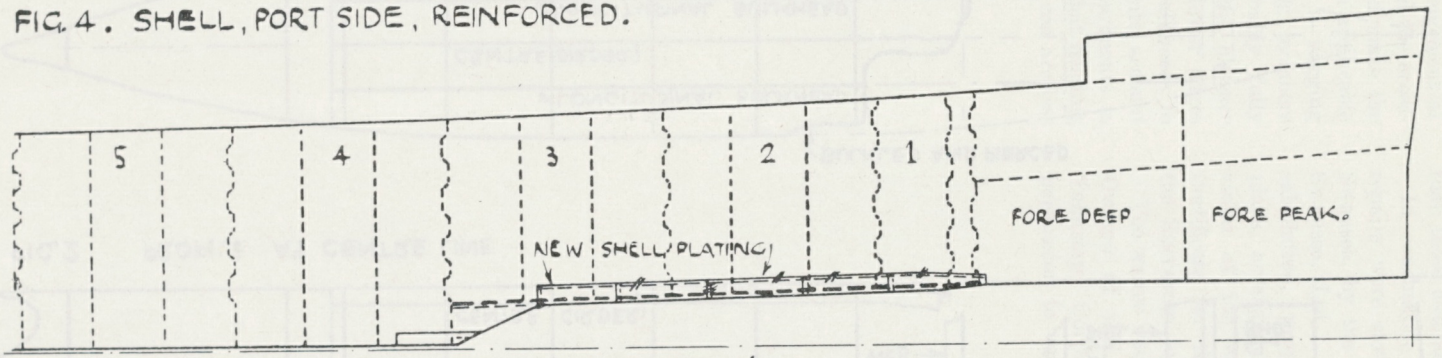
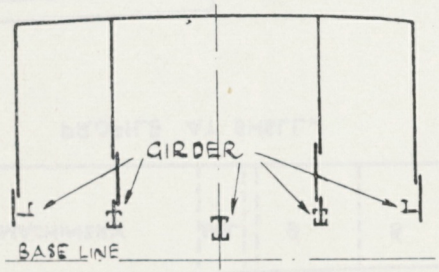
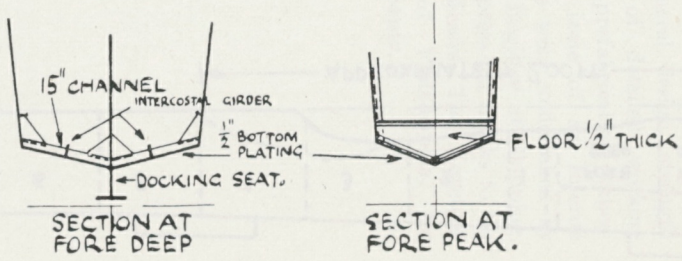


FIG. 5. SHELL, STARBOARD SIDE, REINFORCED.



SECTION AT No 3



SECTION AT FORE DEEP

SECTION AT FORE PEAK.

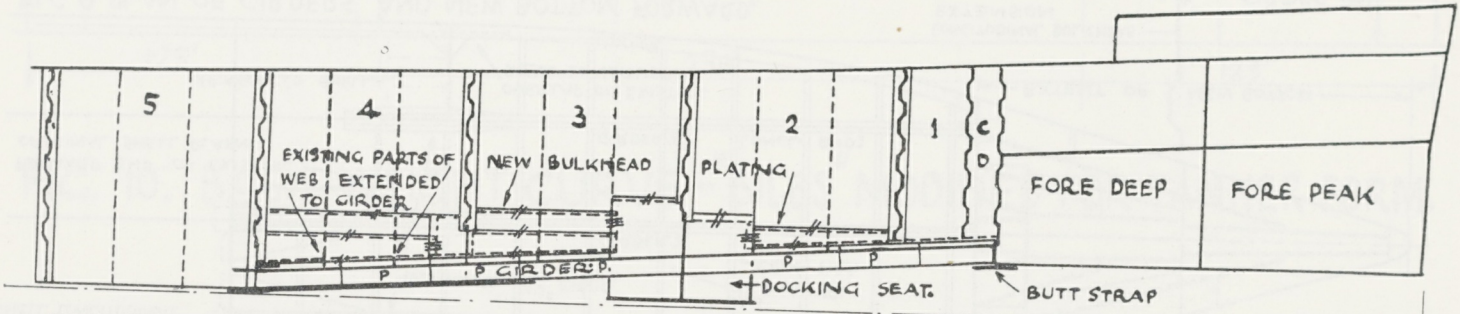


FIG. 6. LONGITUDINAL BHD, PORT SIDE, REINFORCED.

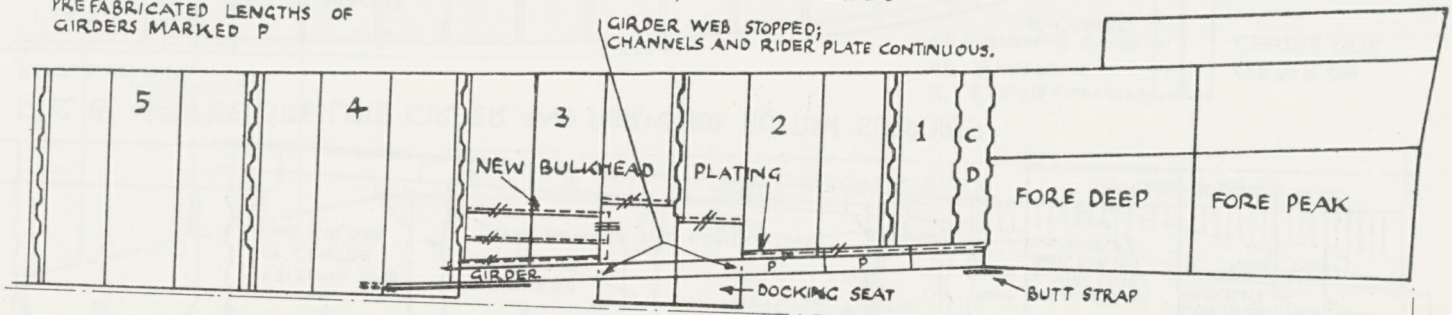


FIG. 7. LONGITUDINAL BHD, STARBD SIDE REINFORCED.

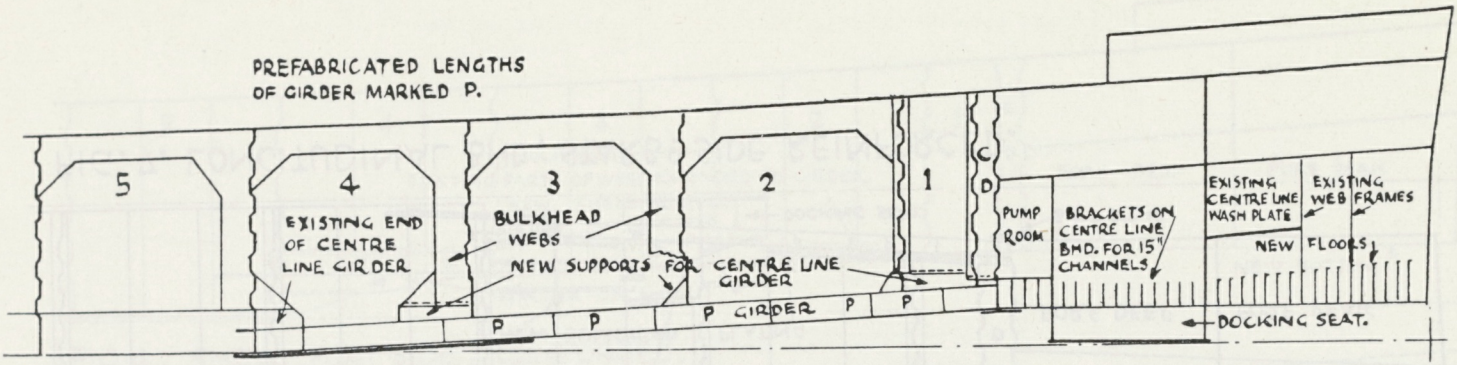


FIG. 8. NEW CENTRE LINE GIRDER AND FORWARD BOTTOM SUPPORTS

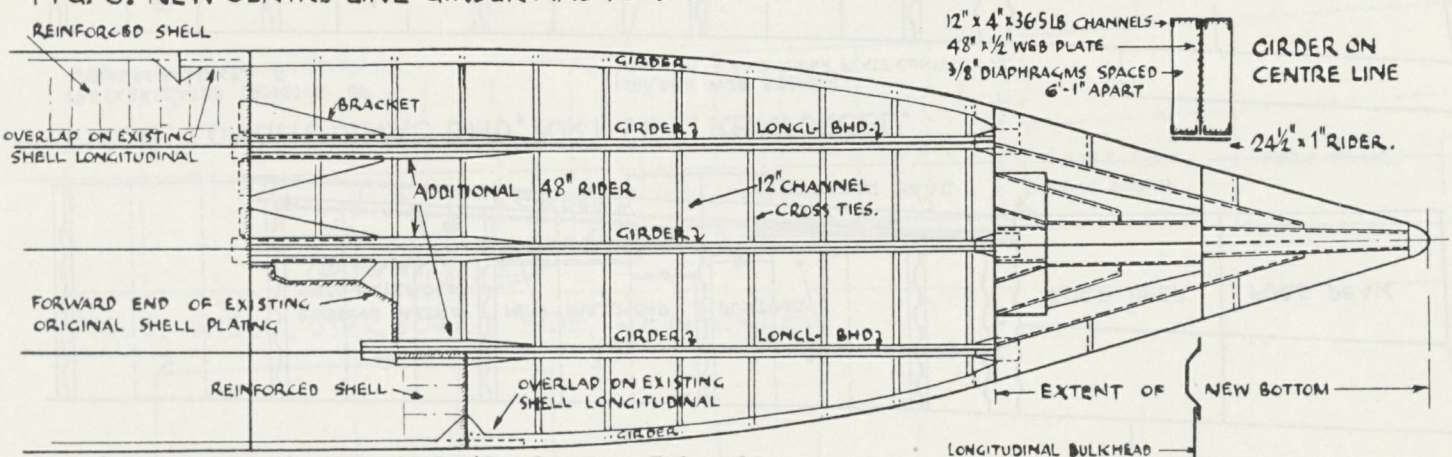
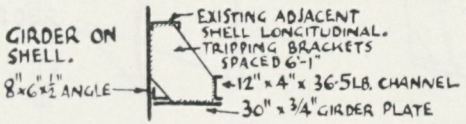


FIG. 9. PLAN OF GIRDERS AND NEW BOTTOM FORWARD.



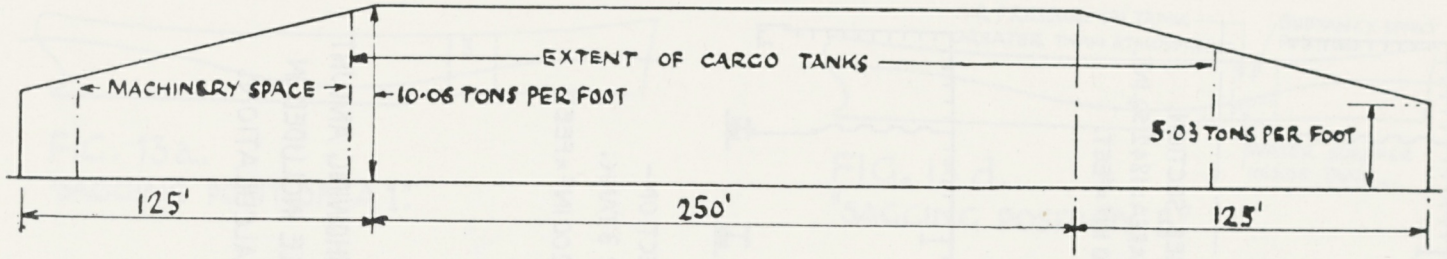


FIG. 10. BASIS WEIGHT CURVE - "BILES" MODIFIED FOR TANKER FORM.

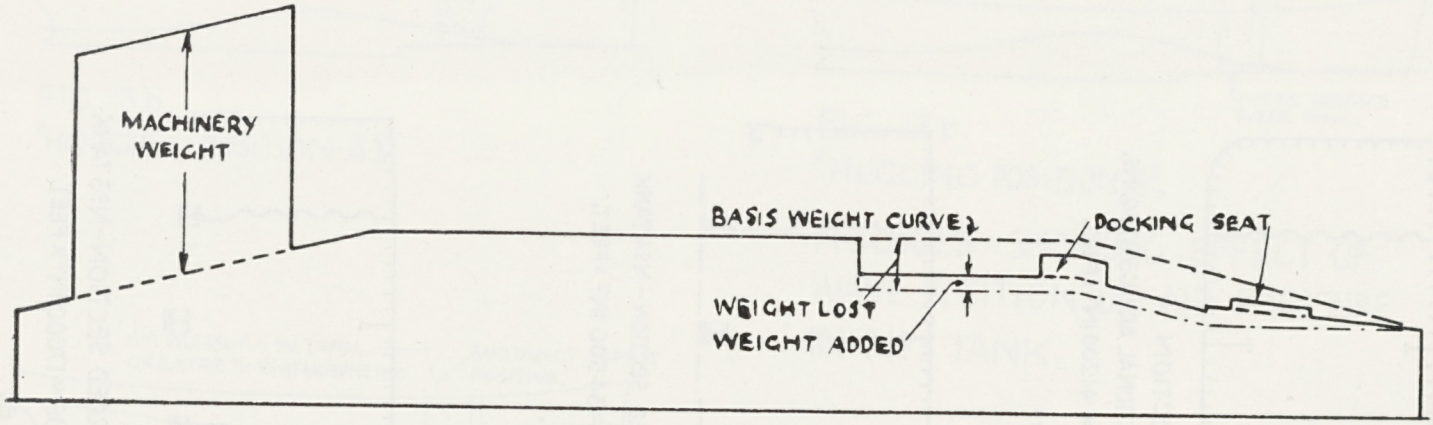
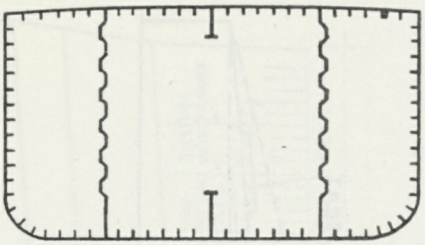
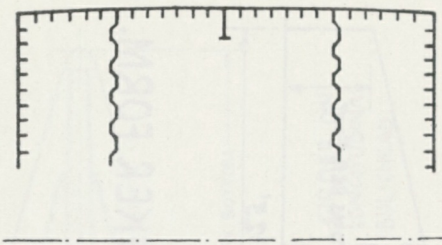


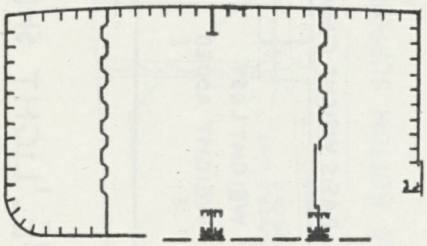
FIG. 11. FINAL WEIGHT CURVE. 'LIGHT SHIP' ONLY.



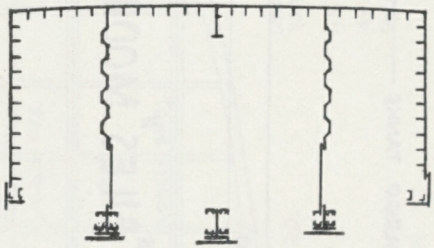
INTACT SECTION
CROSS-SECTIONAL AREA: 3187 SQ. INS.
MODULUS = 41200 IN^2 × FEET.
FIG. 12a.



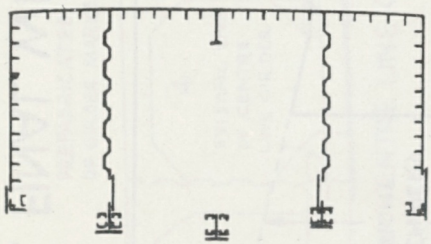
AVERAGE DAMAGED SECTION.
CROSS-SECTIONAL AREA: 1842 SQ. INS.
MODULUS = 7380 IN^2 × FEET.
FIG. 12b.



REINFORCED SECTION – Nº 4 TANK
MODULUS = 34500 IN^2 × FEET.
FIG. 12c.



REINFORCED SECTION –
AFT END OF Nº 3 TANK.
MODULUS = 21200 IN^2 × FEET.
FIG. 12d



REINFORCED SECTION – Nº 3 TANK
MODULUS = 17000 IN^2 × FEET.
FIG. 12e.

FIGS. 12a-e SHOWING AMOUNT OF STRUCTURE INCLUDED IN MODULUS CALCULATION.

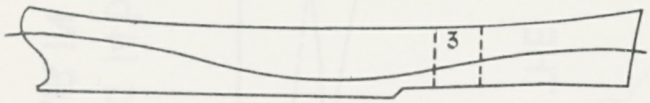


FIG. 13a.
"SAGGING POSITION A1".

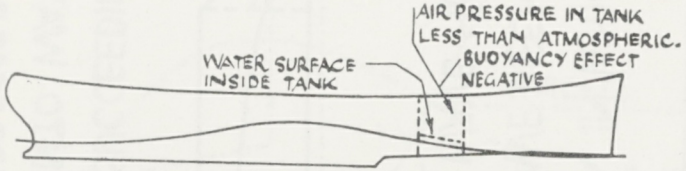


FIG. 13b.
"HOGGING POSITION A1"

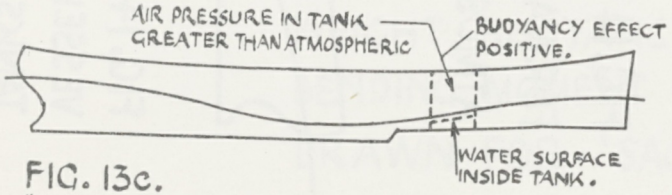


FIG. 13c.
"SAGGING POSITION A2"

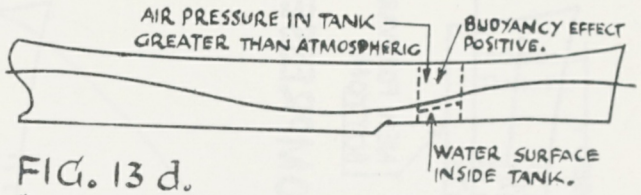


FIG. 13d.
"SAGGING POSITION B"

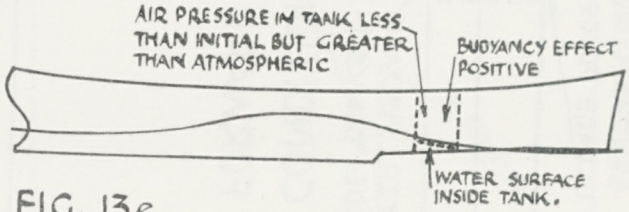


FIG. 13e.
"HOGGING POSITION B".

FIGURES SHOWING EFFECT OF WAVE POSITION ON AIR PRESSURE IN No3 TANK.

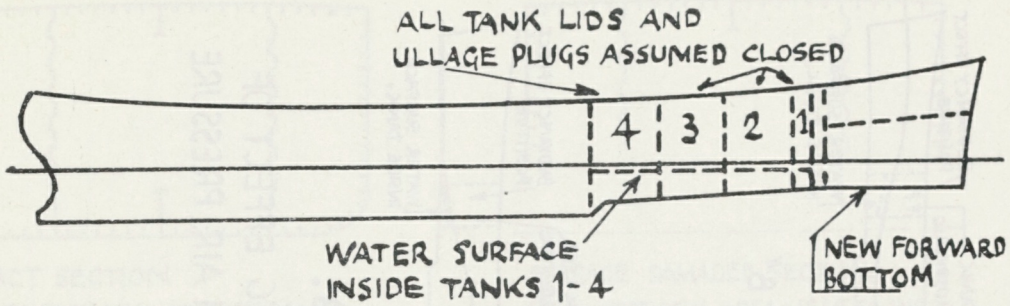


FIG. 14a INITIAL CONDITION WITH COMPRESSED AIR IN DAMAGED FORWARD TANKS.

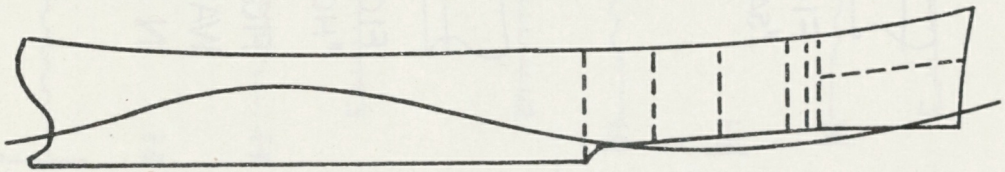


FIG. 14b. CONDITION IN WHICH DAMAGED FORWARD TANKS HAVE BEEN OPENED TO THE ATMOSPHERE BY A WAVE HOLLOW.

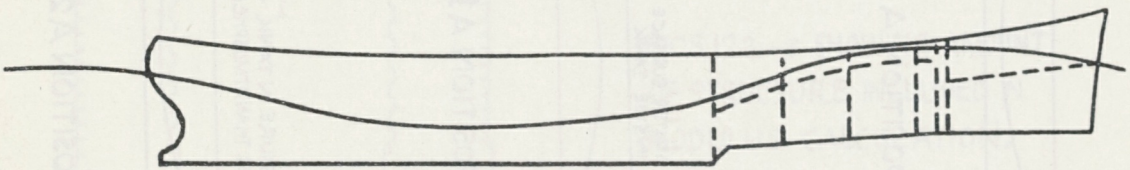
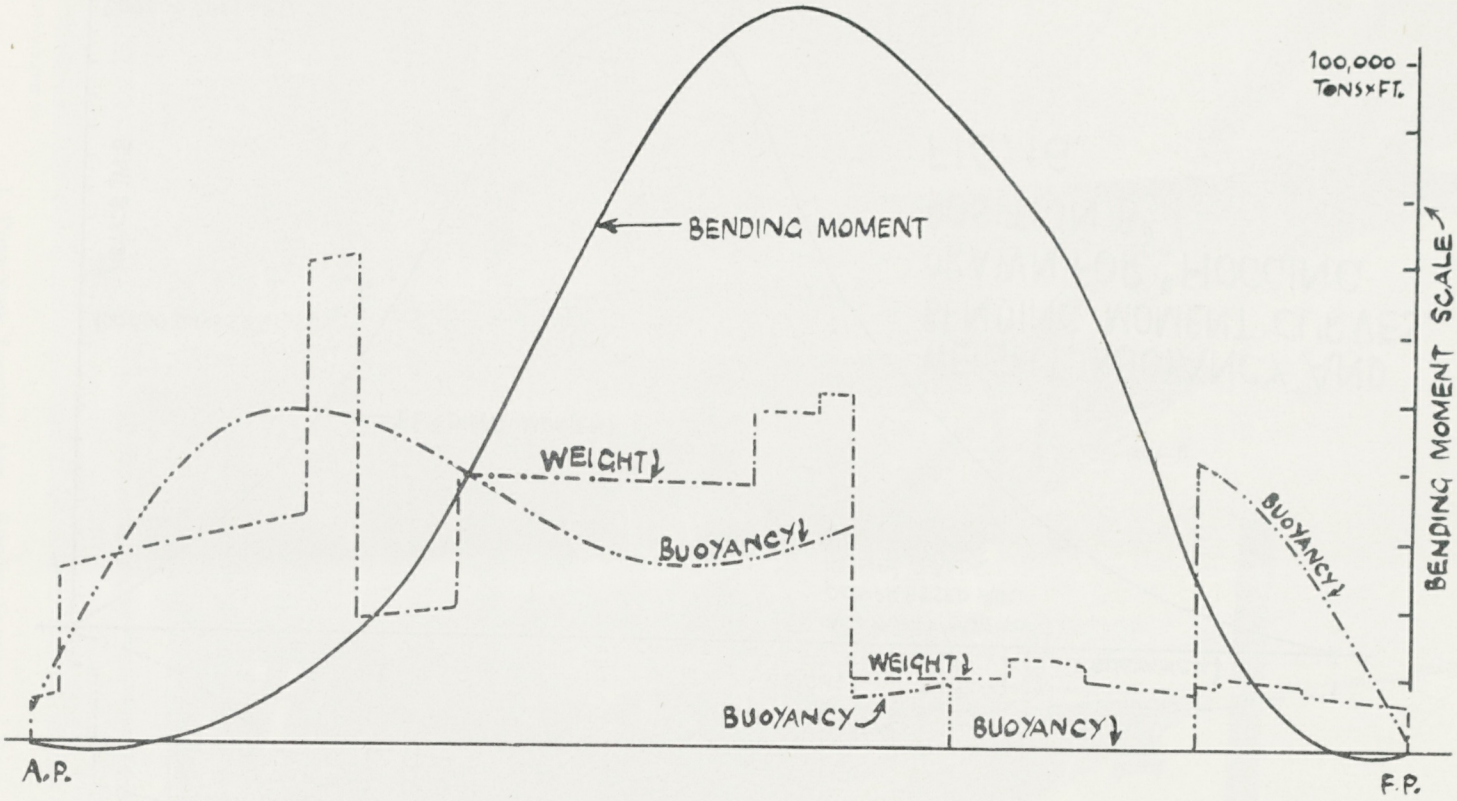
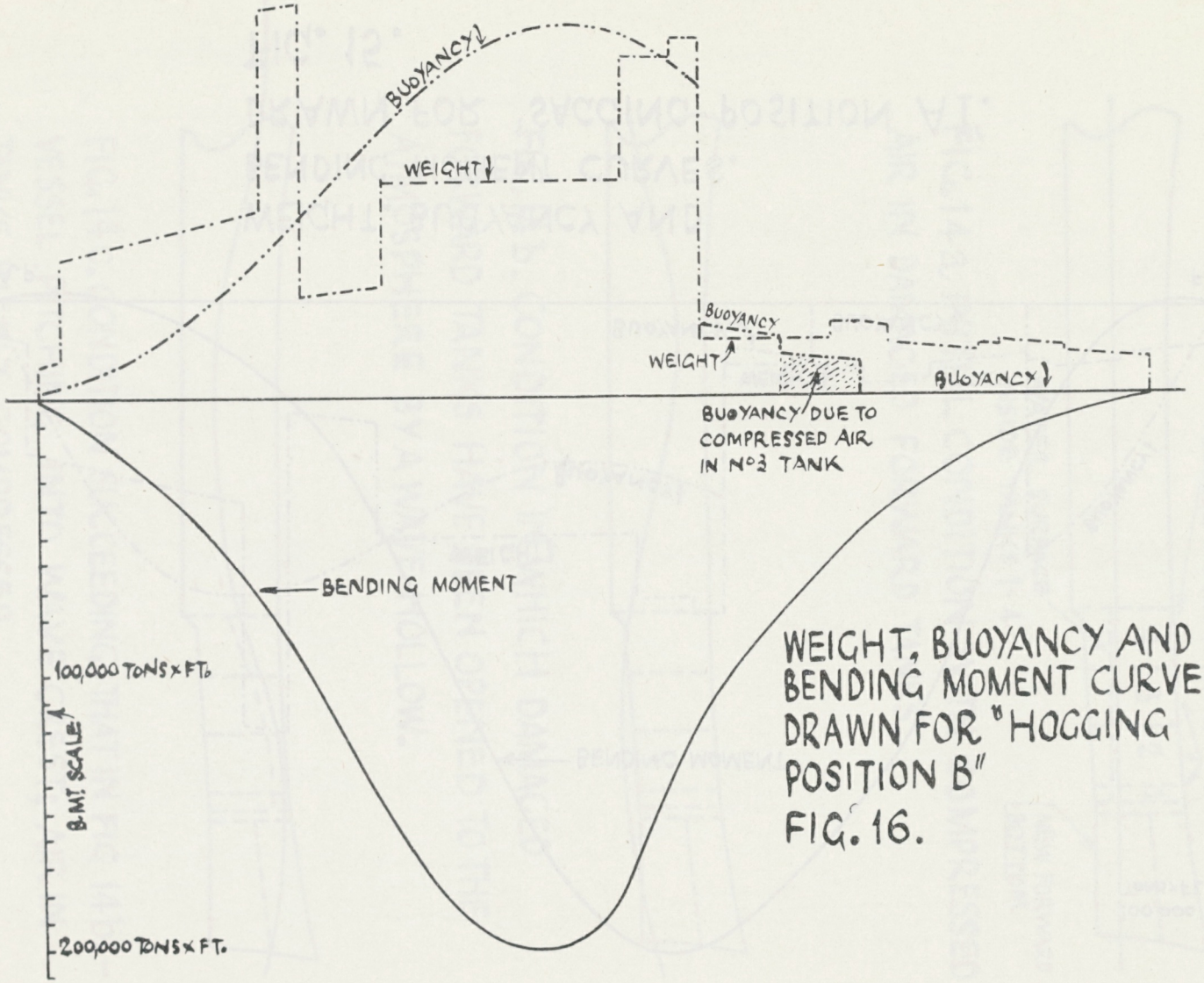


FIG. 14c. CONDITION SUCCEEDING THAT IN FIG 14b:- VESSEL PITCHING INTO WAVE CREST; AIR IN TANKS HIGHLY COMPRESSED.

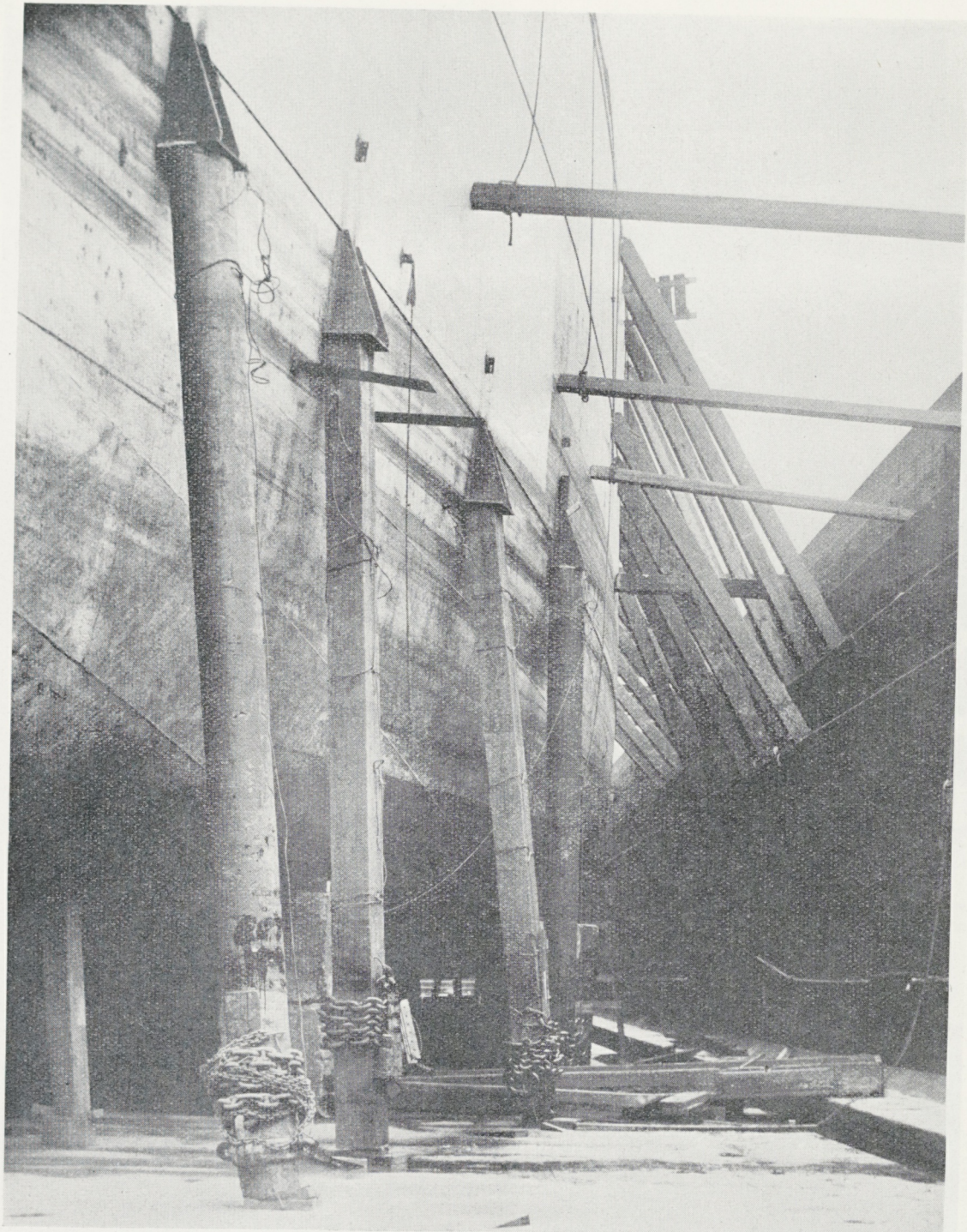


WEIGHT, BUOYANCY AND
BENDING MOMENT CURVES.
DRAWN FOR 'SAGGING POSITION A1'.
FIG. 15.



WEIGHT, BUOYANCY AND BENDING MOMENT CURVES. DRAWN FOR "HOGGING POSITION B"

FIG. 16.



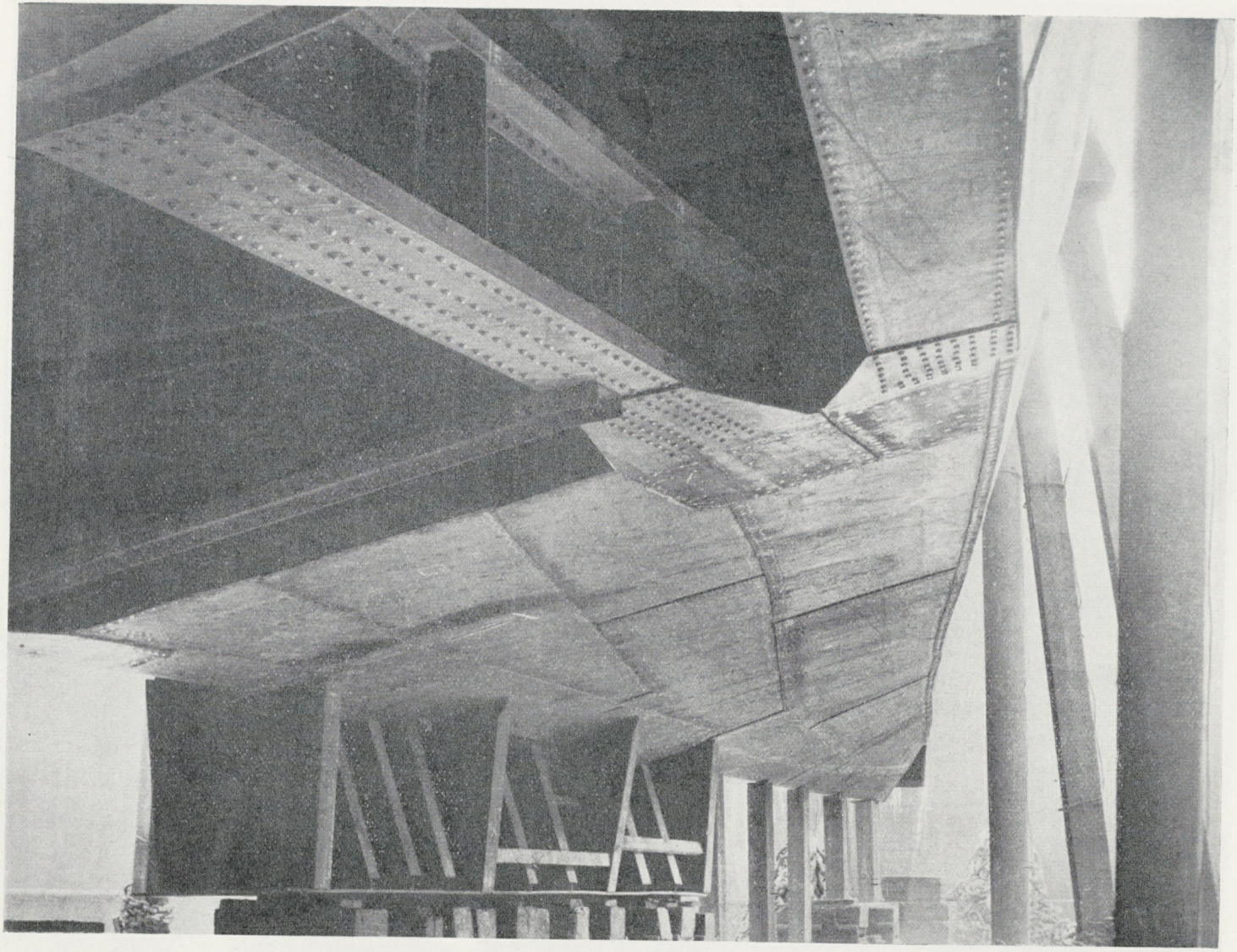
PHOTOGRAPH BY C. H. FARMER, BARRY.

I. PORT SIDE, LOOKING AFT. SHORES SUPPORTING FORWARD END.

PHOTOGRAPH BY

II. STARBOARD SIDE, FORWARD. DAMAGE AT FORE PEAK AND FORE DEEP TANK.

C. H. FARMER, BARRY.



PHOTOGRAPH BY

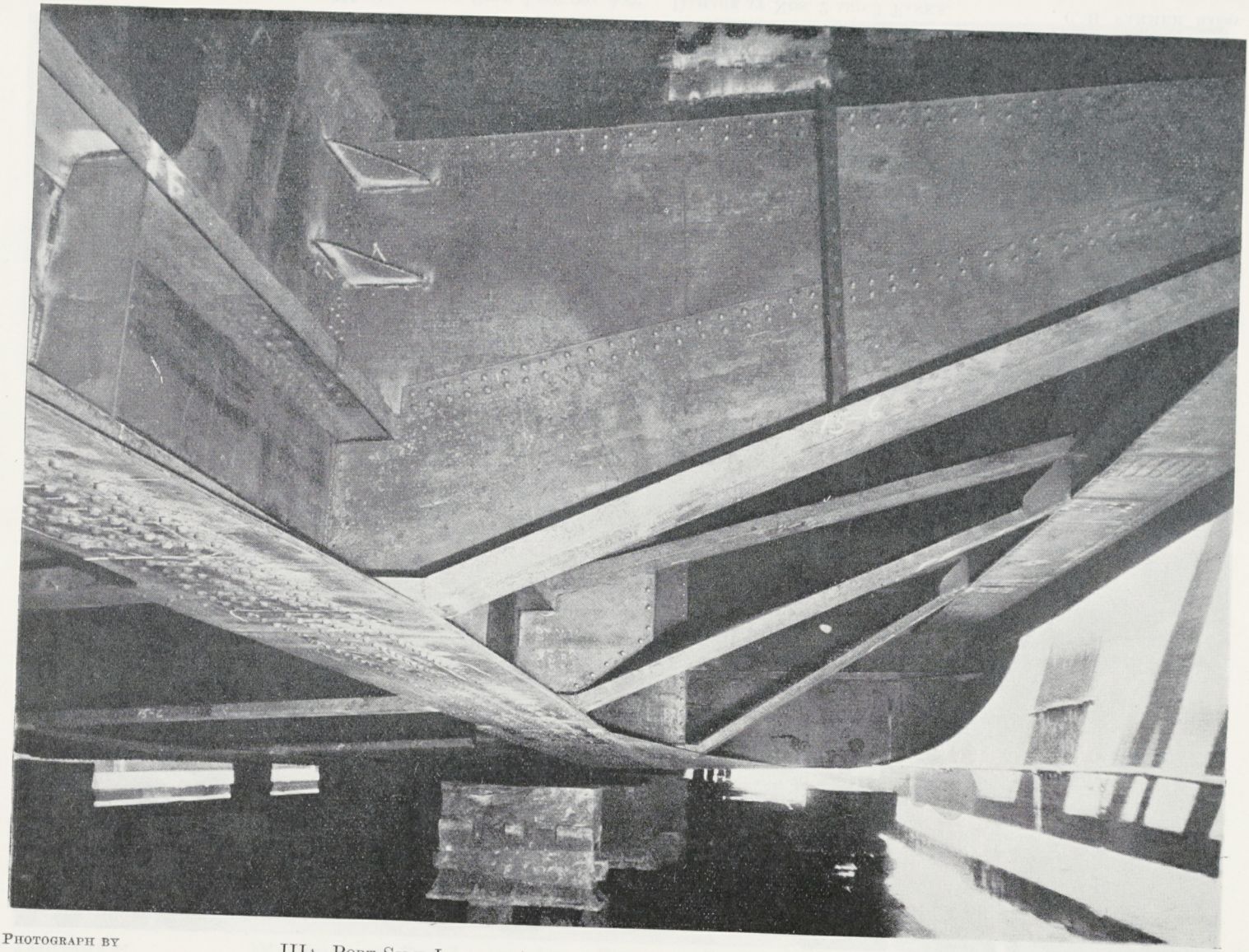
IIA. STARBOARD SIDE, FORWARD. NEW BOTTOM AND FORWARD DOCKING STOOL.

C. H. FARMER, BARRY.

PHOTOGRAPH BY

III. PORT SIDE, LOOKING AFT.—DAMAGE AT NOS. 3 AND 4 TANKS.

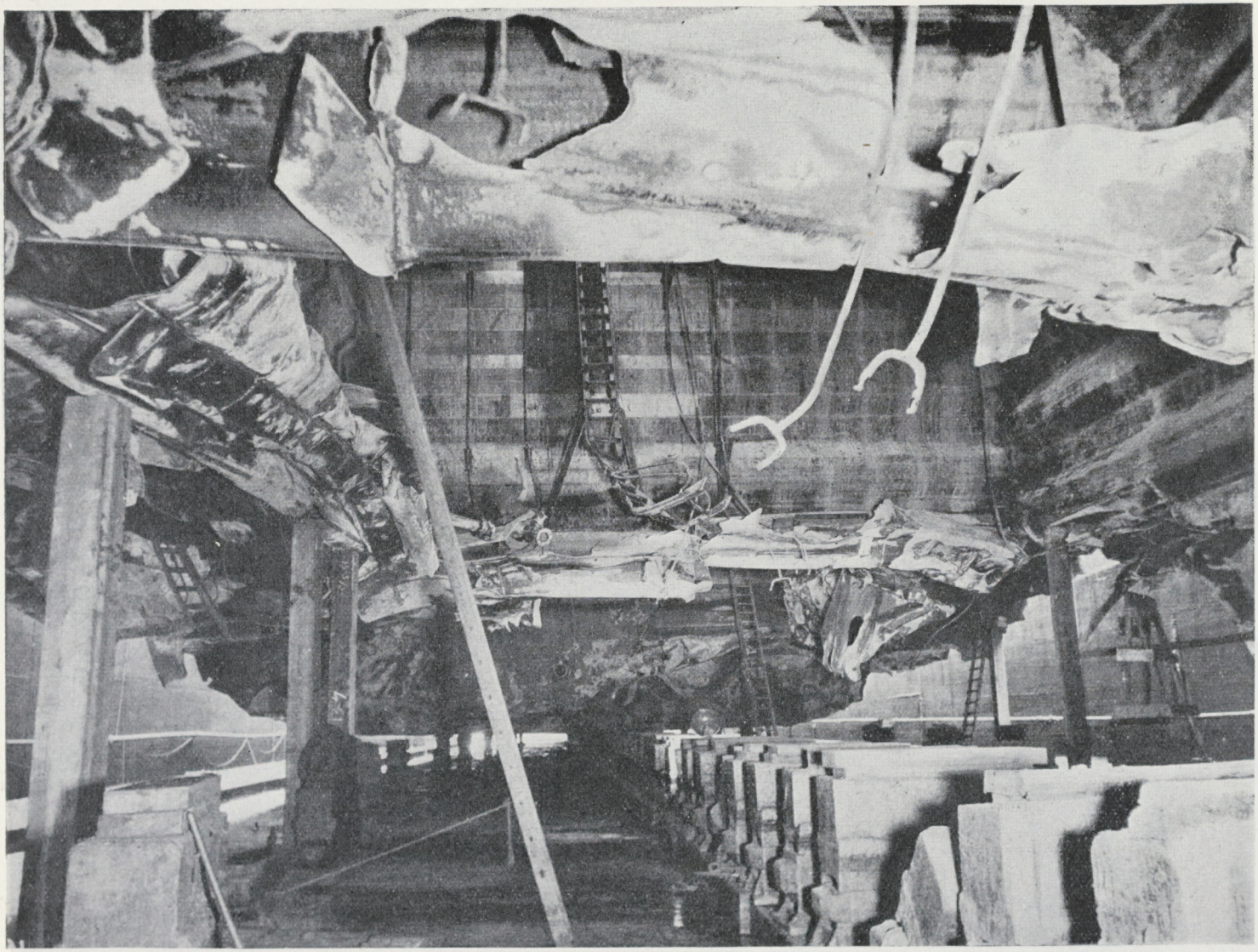
C. H. FARMER, BARRY.



PHOTOGRAPH BY

IIIa. PORT SIDE, LOOKING AFT. TEMPORARY REPAIRS AT NOS. 3 AND 4 TANKS.

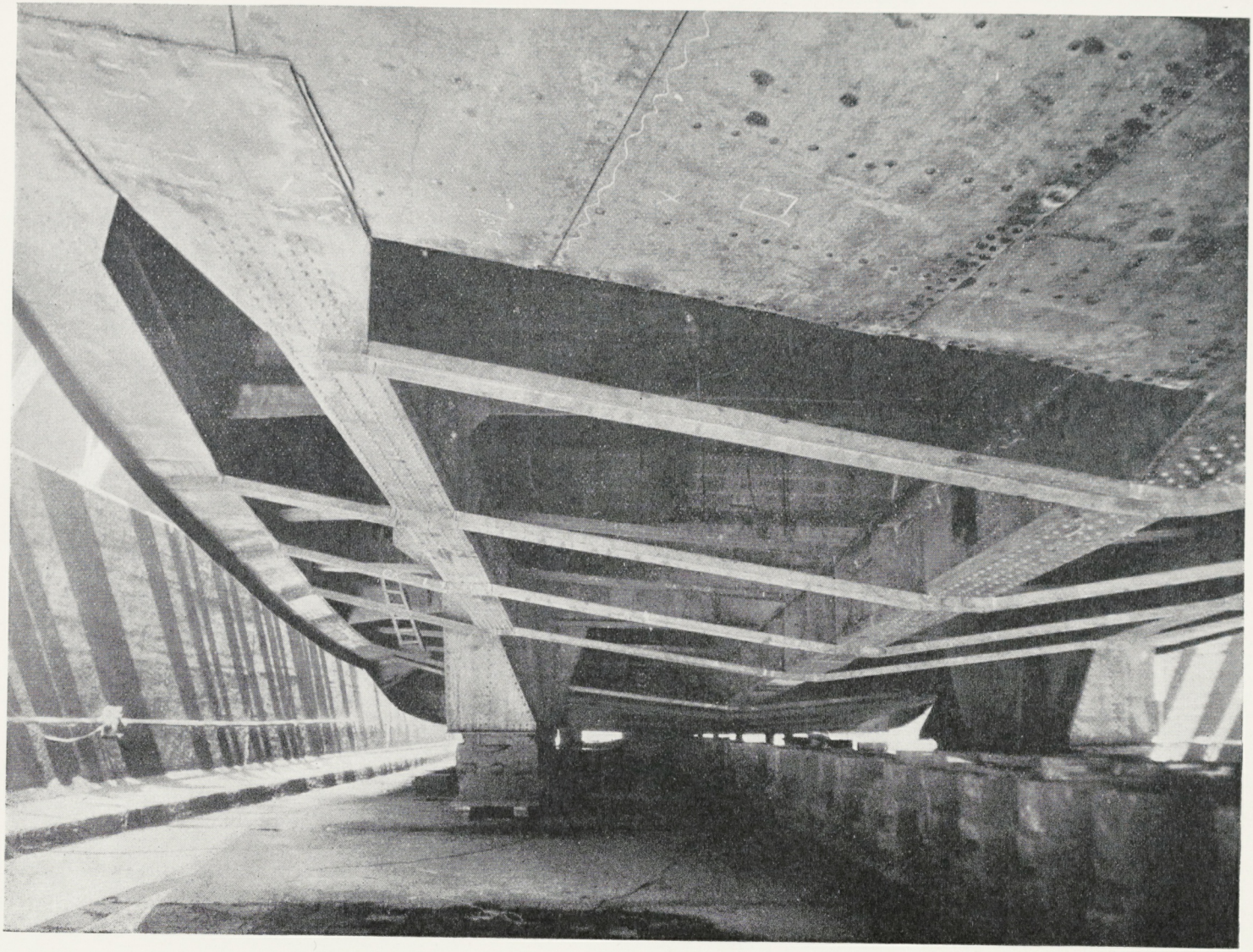
C. H. FARMER, BARRY.



PHOTOGRAPH BY

IV. STARBOARD SIDE, LOOKING AFT. DAMAGE AT NOS. 2 AND 3 TANKS.

C. H. FARMER, BARRY.



PHOTOGRAPH BY

IVA. STARBOARD SIDE, LOOKING AFT. TEMPORARY REPAIRS AND DOCKING STOOLS.

C. H. FARMER, BARRY.

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1946

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SESSION 1946-47.

DISCUSSION AND AUTHOR'S REPLIES

on

Mr. A. Reid's Paper

TEMPORARY HULL REPAIRS

TO THE

TANKER "MARKAY."

LLOYD'S REGISTER OF SHIPPING,
71, Fenchurch Street,
LONDON, E.C.3.

The Author of this paper retains the right of subsequent publication, subject to the sanction of the Committee of Lloyd's Register. Any opinions expressed and statements made in this paper and in the subsequent discussion are those of the individuals.

DISCUSSION ON MR. A. REID'S PAPER ON "TEMPORARY HULL REPAIRS TO THE TANKER 'MARKAY'."

MR. W. THOMSON.

The repair described in this paper is certainly unique, and we are fortunate in having full particulars placed on permanent record by Mr. Reid.

When the case was first discussed in this office, it appeared a rather hopeless proposition, but a little consideration showed that structurally the absence of buoyancy in the forward tanks had not the serious effects that a casual examination would suggest, as the loss of buoyancy was accompanied by a loss of weight.

An examination of the strength curves for normal loading showed that in the hogging condition the loss of buoyancy at the forward end was so nearly equal to the loss of weight that the curve of loads was little affected, and that in the sagging the effect was not of great magnitude.

Taking these considerations into account, together with the fact that the proposed voyage was to be at a moderate draught only, it became apparent that to make the proposition practicable the difficulties to be solved lay in the provision of sufficient strength in way of the damaged portion of the ship to withstand the stresses likely to be encountered, and the calculated bending moments showed that the amount of material required was by no means excessive.

The figures given in the paper indicate how this result was obtained, and the ingenuity of our colleagues in South Wales deserves the highest credit. As shown in the paper, the case appears straightforward, but gives no indication of the numerous alternatives worked out by Mr. Reid, and when I had the privilege of examining his figures I was impressed with the number of suggestions which had been investigated. It was finally decided that compressed air should be provided in No. 3 tank, but this conclusion was reached only after it had been found that to make similar provision in additional tanks would lead to increased stresses.

I am not quite clear as to the value of the arrangement of compressed air, since the author states that at atmosphere pressure the differences in the calculated stresses were small, while if compressed air were supplied the tank might be opened to the atmosphere in a wave hollow and the value of this precaution would disappear. Perhaps Mr. Reid could tell us if there would have been an appreciable increase in the calculated stresses.

The author has modestly omitted to refer to the very active part which he played in the design of the reinforcement of the bottom of the ship. When I saw the vessel in dry dock I congratulated the manager on the efficient work of his drawing office in the preparation of the plans for this unusual type of repair and the excellence of the arrangements for prefabrication, but he assured me he had no drawing office and that all the plans and specifications had been prepared by Mr. Reid, without whose co-operation he would not have been able to carry through the contract.

MR. A. W. JACKSON.

We at Liverpool carried out extensive repairs to mined and torpedoed vessels, but time did not permit of any strength calculations being made.

Generally speaking, we were expected to make our recommendations at a round table conference of all interests concerned after an examination of the damage.

Referring to the buoyancy conditions at the bottom of page 6 in the first column, it is a little difficult to see that the water level inside No. 3 tank would be higher than the outside.

MR. P. T. BROWN.

Although, in war, economic considerations have to give way to operational needs—and in 1943-44 we certainly needed tanker tonnage—there are doubts as to whether the decision to salvage and repair was a good one. Dry docks were in great demand, and their occupation, whether on this or on the other side of the Atlantic, for very long periods was of strategic importance. Tugs and salvage gear were equally in great demand, but above all man power was very limited. Our steel works, too, were stretched to capacity, and much material had to be imported from America.

If Mr. Reid has any information of the total costs involved from the stranding to eventual recommissioning of this vessel, and the dry dock time involved, it would be a matter of much interest.

MR. THOS. P. GIBBESON.

Speaking as an engineer, it would be interesting to know if the machinery suffered in any way when the vessel went aground, and if any of the machinery parts were opened up for survey as a precautionary measure. Did the propeller sustain any damage, e.g., blade tips bent or broken, and, if so, was the tail shaft checked for alignment? Were the ship's side fittings examined for fractures and the outside fastenings cleared if choked? At what speed was the vessel travelling when she went aground off the Island of Skye, and was she able to get off under her own power, or had she to be towed off?

MR. H. L. WALKER.

We are indebted, Mr. President, to the author for his Paper by which he has enabled us to share in his experience on this temporary repair.

Is it correct to assume that the compressed air equipment, used before and after temporary repairs, was part of the vessel's initial equipment without reinforcement?

The author has indicated that consideration was given to permanent repairs. Could he give his opinion upon whether or not this modern tanker, with corrugated and all-welded bulkheads and completely—or almost completely—welded bottom structure, could have been restored to her original condition in an economic period by repairers in the Bristol Channel?

It is noted that large brackets have been fitted at the aft end of the girders where necessary to avoid abrupt change of section, and, whilst it is remembered the forward ends of the girders are well towards the bow of the vessel, one is struck by the small area and spread of the brackets attaching the girders, by a long overlap, to the new temporary bottom plating; this is strikingly illustrated in photograph IVa.

For our further information, could the author indicate if it was considered necessary to reinforce the forward bulkheads of No. 5 tank, port and centre, and No. 4 tank starboard.

It is assumed that the agreed draught for the Atlantic crossing, namely 18 feet forward and 22 feet aft, was that which gave the greatest draught forward, together with reasonable submersion of the propeller; but if this is not so, could the author state the reason for limiting the draught forward, since an increase would have lessened the possibility of No. 3 tank being opened to the sea in a wave hollow? To obtain an increase in draught forward, it is not suggested that the fore deep or fore peak should have been filled.

The author has given the weight of steel torn and removed from the vessel, but it would be of interest if he could add the weight of steel fitted into the vessel, together with the time taken for repairs since, for each, only approximations are possible from the information given.

It would seem a splendid arrangement that docking stools should be fitted, but, in view of material and labour shortages, it is not clear why they should be so deep since strong level surfaces would appear to be all that are necessary provided their position and height be available for the next dry docking.

MR. A. G. AKESTER.

The case of the "Markay" is a most interesting one. This tanker grounded on the Northern Coast of Skye on the 15th November, 1943, and came off under her own power with compressed air plant in operation on the morning of the 17th November. "Markay" was subsequently examined in Kames Bay, Isle of Bute, when a diver reported serious bottom damage extending generally as since indicated in the paper.

So far as the above-water portion of the vessel was concerned no damage was visible.

The vessel was floating at draughts 21 feet 9 inches aft and 19 feet 6 inches forward. When seen on the 23rd November the air compressor had not run for twenty-four hours, and this was reported to have made an addition to the draughts of about 12 inches. The after compressor was started up and the vessel's bow rose some 9 inches in about an hour. Occasional air bubbles were noticed on the starboard side in two places.

It was thought likely that when placed in dry dock considerable repairs, whether of a temporary or permanent nature, would be necessary before the vessel could go elsewhere, and the paper records the temporary repairs eventually effected to enable "Markay" to proceed to the U.S.A. As is often the case, the "temporary" repairs proved to be more of a problem, and certainly much more interesting to effect, than the permanent ones.

If I remember aright, it was suggested that the diver who first inspected the vessel should be in attendance at the docking to assist in supporting the damaged portion, since he best knew the extent of the damage, but I do not think this was done. The docking must have been a tricky job!

Can the author say whether the voyage was uneventful and whether any modification of the restricted use of the compressed air became necessary.

It would be of interest also to know if "Markay" sailed by way of the Azores.

The restoration of the buoyancy in way of fore peak and deep tank could be an aid and, in certain conditions, a menace to the navigation of the ship, and this would seem also to apply to the use of compressed air.

It will always be open to conjecture whether "Markay" could have returned to the U.S.A. in her fully damaged condition, but there is no doubt she would have been a bad risk.

MR. J. S. ORMISTON.

This paper is an account of a remarkable temporary repair and so merits an honoured place in the Transactions of the Association.

As it deals with a *fait accompli*, there seems not a great deal one can criticise, but one or two queries suggest themselves.

The first is: Would it be possible for the author to tell us something of the weather experienced by the ship on her voyage across the Atlantic to the U.S.A.? This was indeed in the summer season, but the North Atlantic can be angry at all seasons; also was any damage found when the ship was dry docked for permanent repairs. Again, could the author indicate in his reply the normal draughts forward and aft in undamaged condition.

Looking at Figs. 4, 5, 6 and 7, we see that this vessel in the temporarily repaired condition has her proportions of length to depth considerably reduced from the forward half length to fore end of ship. Her length is 13½ times her depth amidships and, as nearly as one can scale from the diagrams, this proportion at half length forward would be about 12½ in undamaged condition, but as temporarily repaired, about 14½ at the fore end of the docking seat which straddles the bulkhead between Nos. 2 and 3 tanks, which is not far from half length forward; thus this increased flexibility must have been felt if the ship had met with heavy weather.

It is presumed all the Section Moduli in Figs. 12A to 12E are at the bottom, including that for the intact section, but perhaps the author could make this clear; further, would he indicate the stresses of the top and bottom of the girder

at the maximum B.M. Ordinates of Figs. 15 and 16 which occur on the intact structure? Specially does this appear to be so in Fig. 16.

I think also it would complete the picture if the author could show the Shearing Force Curve on Figs. 15 and 16.

Another point of interest, I think, might be to show the position vertically of the neutral axis from about amidships forward to cover the part of the ship where there is no bottom plating. I imagine this axis must be nearer the deck than for the undamaged structure.

MR. ALFRED HEAD.

As the author states, after agreeing upon the cross sectional area to be restored, one of the important obstacles to be overcome was that of avoiding abrupt change of area at the junction with the existing structure, and this appears to have been successfully achieved by means of rider plates. It would be of interest to learn whether any cracking or deformation was noted when the vessel refloated after temporary repairs, and whether deck sights were set up prior to the first dry docking and checked when the vessel refloated. Details of the readings would add further to the value of the paper, together with any data of the voyage over to the U.S.A., any unusual movements and whether any excessive settling was noted when the vessel dry docked for permanent repairs, and whether there was much deformation of the structure when temporary repairs were being released.

As the vessel was of a combined riveted and welded type, the author would have a good opportunity of noting whether either type of connection had suffered more by the damage.

It is good to read that the full responsibility for the original proposals, through the design stages and the practical application, to the issue of an Interim Certificate rested with the Surveyors to Lloyd's Register of Shipping.

REPLIES.

To all of his colleagues who have made a contribution to the discussion and made appreciatory comment on his essay the writer has much pleasure in expressing his thanks. In what follows he hopes that satisfactory answers will be found to the questions that have been asked.

To Mr. W. Thompson.

The writer is of the opinion that there would have been no appreciable alteration in the calculated stresses if the ullage plugs in the closed hatchway lids of No. 3 tank had been left open, as they were on the other tanks; the buoyancy effect from the air in the tank was relatively small and its centre of effort was near the aft end of No. 4 tank so that the bending moment effect at the aft end of No. 4 tank would be small.

The main advantage in having the lids and ullage plugs closed was that in the event of the temporary bottom forward being damaged and developing a leak, some reserve buoyancy would have been at once available, this adding to the safety of the ship during the interval that would have elapsed while ullage plugs in other tanks were being closed. It was realised that, apart from that state of emergency, compression might be lost in No. 3 tank during the passage of a wave hollow; but initial conditions would have been restored when the hollow had passed.

To Mr. A. W. Jackson.

The writer offers his apologies for the error in the statement of the buoyancy condition at the foot of the first column on page 6. The sentence beginning "At this stage the air in the tank" should end with "the water level outside would be higher than that inside and the air would have a buoyancy effect."

The recommendations for repair were made at a round-table conference—admittedly after some rough estimates of stress had been made. The

more detailed calculations merely confirmed the estimates. Many decisions had to be made at the bottom of the dry dock because many points that looked simple on paper presented difficulties at the ship. Such minor details as slight buckling of plating, not noticed perhaps until a new plate was placed in position, caused a certain amount of trouble; so, too, did the rather complicated structure at the junction of the corrugated transverse and longitudinal bulkheads.

To Mr. P. T. Brown.

The writer finds it rather difficult to answer the doubts as to whether or not the decision to salvage and repair was a good one. Probably the shortage of tankers influenced the authorities in their decision to grant a license, and hence the temporary repairs made.

The vessel was in dry dock from the middle of December, 1943, to the beginning of May, 1944. The damage repairs were not begun until about the end of January.

The writer cannot give the total cost incurred in stranding and subsequent repairs, but he can say that the cost of the repairs, including the fitting of the docking stools, was about eight per cent. of the insured value of the ship.

To Mr. Thos. P. Gibbeson.

The propelling machinery, propeller and rudder sustained no damage at all. Pumps in the forward pump room were, of course, damaged. The ship's side fittings were examined but were found intact; none of the outside fastenings was found choked, probably because the vessel ran aground on a hard bottom. The structural damage at the forward part of the ship ended almost abruptly between Nos. 4 and 5 tanks; aft of that the shell was neally unscratched.

The vessel was proceeding at about 15 knots when she went aground, and, as is stated in the remarks by Mr. Akester, was able to get off the rocks under her own power when the damaged forward end was raised clear of the reef under the action of the compressed air in the forward tanks.

To Mr. H. L. Walker.

The compressed air equipment used at the time of the accident was part of the initial equipment of the vessel; it was due to its being on board that the vessel was able to get off unaided. The equipment had been specially fitted as a safeguard against partial damage by the enemy; it was not part of the vessel's main machinery installation.

The writer is of the opinion that full permanent repairs would have been effected in an economic time in the Bristol Channel. But for this, additional welders would have been required to be drafted to the area. The authorities, however, insisted that they were engaged on important work elsewhere. The Owners' representative was unwilling to accept an all-riveted repair that would have restored the vessel to her original condition. Temporary repairs were therefore effected.

The forward bulkheads of No. 5 tank port and No. 4 tank starboard were reinforced to a certain extent at the lower ends by the cement placed at the bottom of these tanks which, together with the plating welded to the outside over the buckled shell, made these tanks watertight. No. 5 centre tank forward bulkhead was not reinforced, but some ballast was carried during the voyage in all No. 5 tanks, and this was considered sufficient to support the bulkheads against external pressure.

The writer agrees that a greater draught forward would have made less likely the opening of No. 3 tank to the atmosphere. But to get a greater draught forward would have meant, if the fore peak and fore deck were to be kept empty, placing a fairly large quantity of ballast in No. 5 tanks, resulting in a greater change or loading per foot than that in the actual condition for the voyage. A greater draught forward would also have given rise to greater stresses in the sagging condition.

The writer agrees that the labour and material would have been saved by fitting shallower docking stools. This point, however, really did not arise because, although the docking stools were commenced as soon as possible after the vessel was placed in dry dock, and were being

constructed during the interval in which the feasibility of temporary repairs was being examined, it was always hoped that the decision to go ahead with the repairs would be made in due course. With that possibility in view, it was natural to keep the bottom of the stools below the line of the proposed bottom forward and below the line of the proposed girders, and to arrange them so that they would be in part incorporated in the girder structure.

To Mr. A. G. Akester.

Mr. Akester's remarks on the preliminary surveys at the Island of Bute and on the value of the diver's reports are very interesting. As far as the writer knows, the diver who first examined the vessel was not in attendance at Swansea. It is doubtful if further examination by him would have increased the information about the extent of the damage before the vessel was placed in dry dock. As it was, even with divers working in the dock bottom while the ship was being gradually let down on the blocks and shores, the extent of the damage revealed when the dock was emptied came as a surprise to most people concerned.

In reply to Mr. Akester's question about whether conditions, the writer regrets that fuller information on this point was not sought by the writer shortly after the news came through that the ship had arrived. About the most he can say is that the weather was considered average for the time of the year for the greater part of the voyage, with improved conditions during the last three days, when the speed was increased to about ten or eleven knots. The voyage was uneventful. The "Markay" did not sail by way of the Azores, a more northerly route having been followed. No alteration in the use of compressed air was necessary.

To Mr. J. S. Ormiston.

The writer can only refer Mr. Ormiston to the remarks on the weather during the crossing given in the reply to Mr. Akester. No damage was sustained by the temporary repairs during the voyage. The writer assumes that by "normal draughts forward and aft" is meant the normal ballast draught in the undamaged condition; the draughts at which the damaged vessel crossed the Atlantic were practically the normal ballast draughts.

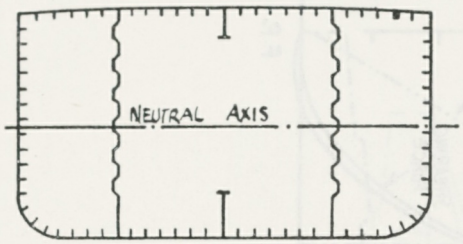
Mr. Ormiston's speculations about the flexibility of the ship and its effect in heavy weather are certainly pertinent. The effect of the new bottom forward pounding in heavy seas would certainly have shaken the forward end to some extent. It was felt, however, that the stresses indicated by the calculations were such that the vessel was likely to be stressed to too dangerously high values.

As Mr. Ormison has assumed, the Section Moduli given in Figs. 12A to 12E were obtained by dividing the moment of inertia about the neutral axis by the distance from the neutral axis to the bottom of the section. The stresses at the deck and keel of the intact section at the position of the maximum bending moments are 2·6 tons in the sagging condition (Fig. 15) and 4·8 tons in the hogging condition.

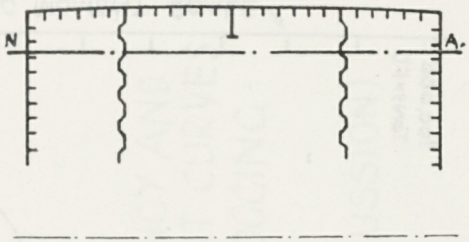
Sketches are included in this reply showing the shearing force curves and the approximate position of the neutral axis at different sections. It will be noticed that the neutral axis is considerably higher in the sections showing the repairs than in the intact section, signifying that the stresses at the deck are correspondingly smaller than those at the keel at the positions given in the table of stresses.

To Mr. Alfred Heap.

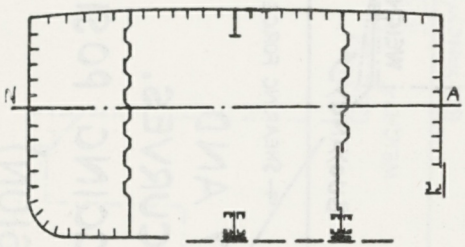
Most of the points raised by Mr. Heap have been answered in the author's replies to other contributors to the discussion, and it is hoped that they will prove sufficient. It should be added that when the vessel was placed in dry dock in America no cracking or deformation was observed. Prior to undocking in Swansea the vessel was sighted and found to have a hog of a few inches. It was the intention of the Owners' Superintendent to remove this hog after the temporary structure had been dismantled in dry dock in America; and in the course of the permanent repairs the hog was reduced to less than one inch.



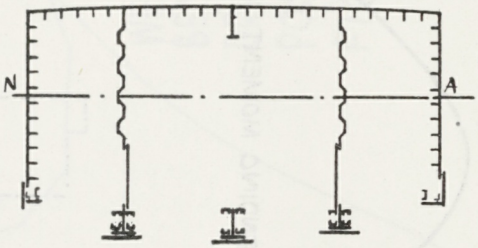
INTACT SECTION
CROSS-SECTIONAL AREA: 3187 SQ.INS.
MODULUS = 41200 IN^2 x FEET.
FIG. 12a.



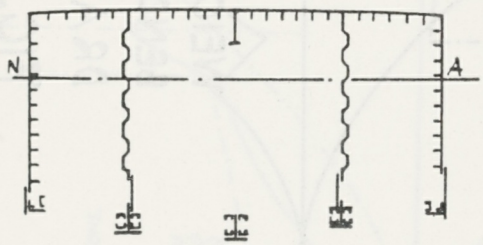
AVERAGE DAMAGED SECTION.
CROSS-SECTIONAL AREA: 1842 SQ.INS.
MODULUS = 7380 IN^2 x FEET.
FIG. 12b.



REINFORCED SECTION - Nº4 TANK
MODULUS = 34500 IN^2 x FEET.
FIG. 12c.



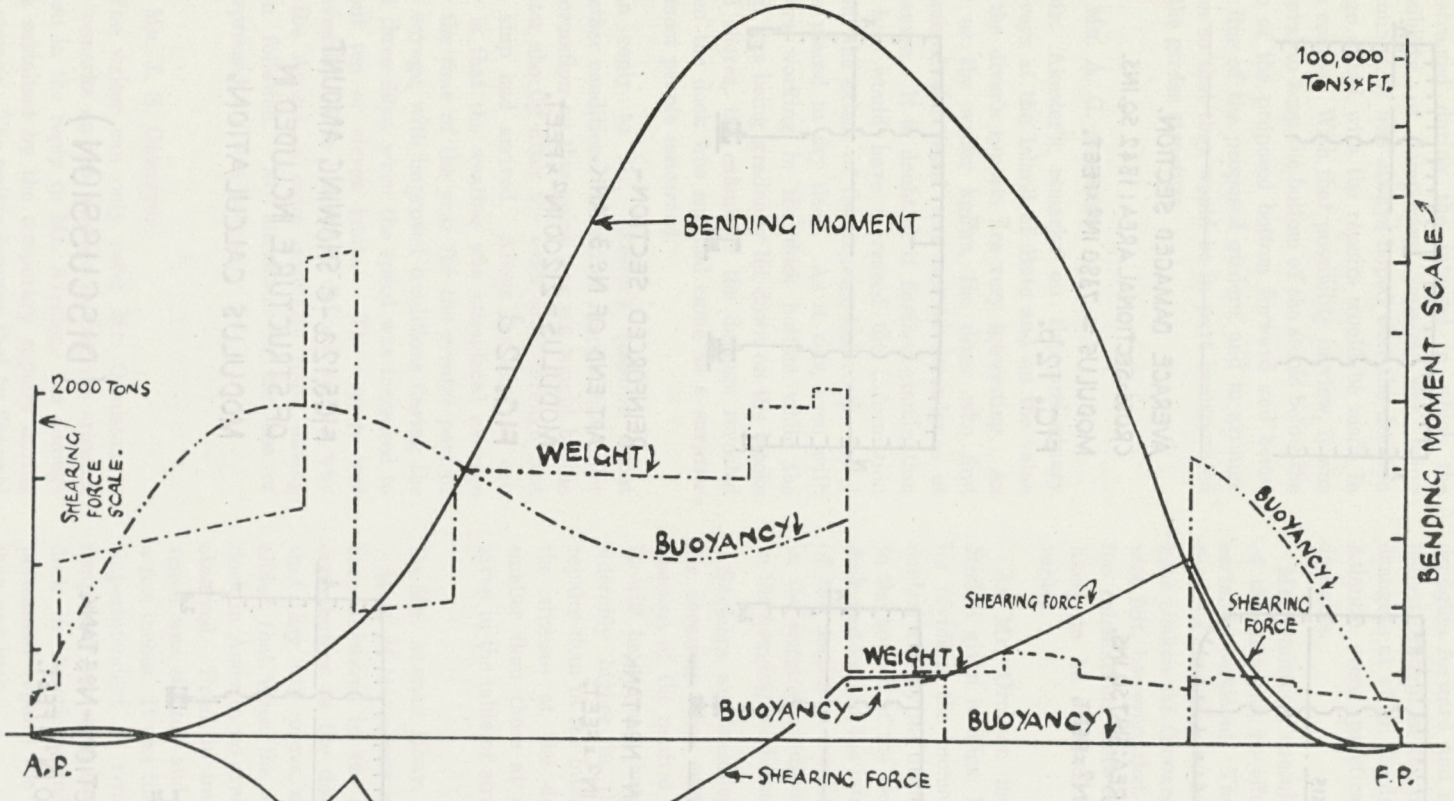
REINFORCED SECTION -
AFT END OF Nº 3 TANK.
MODULUS = 21200 IN^2 x FEET.
FIG. 12d



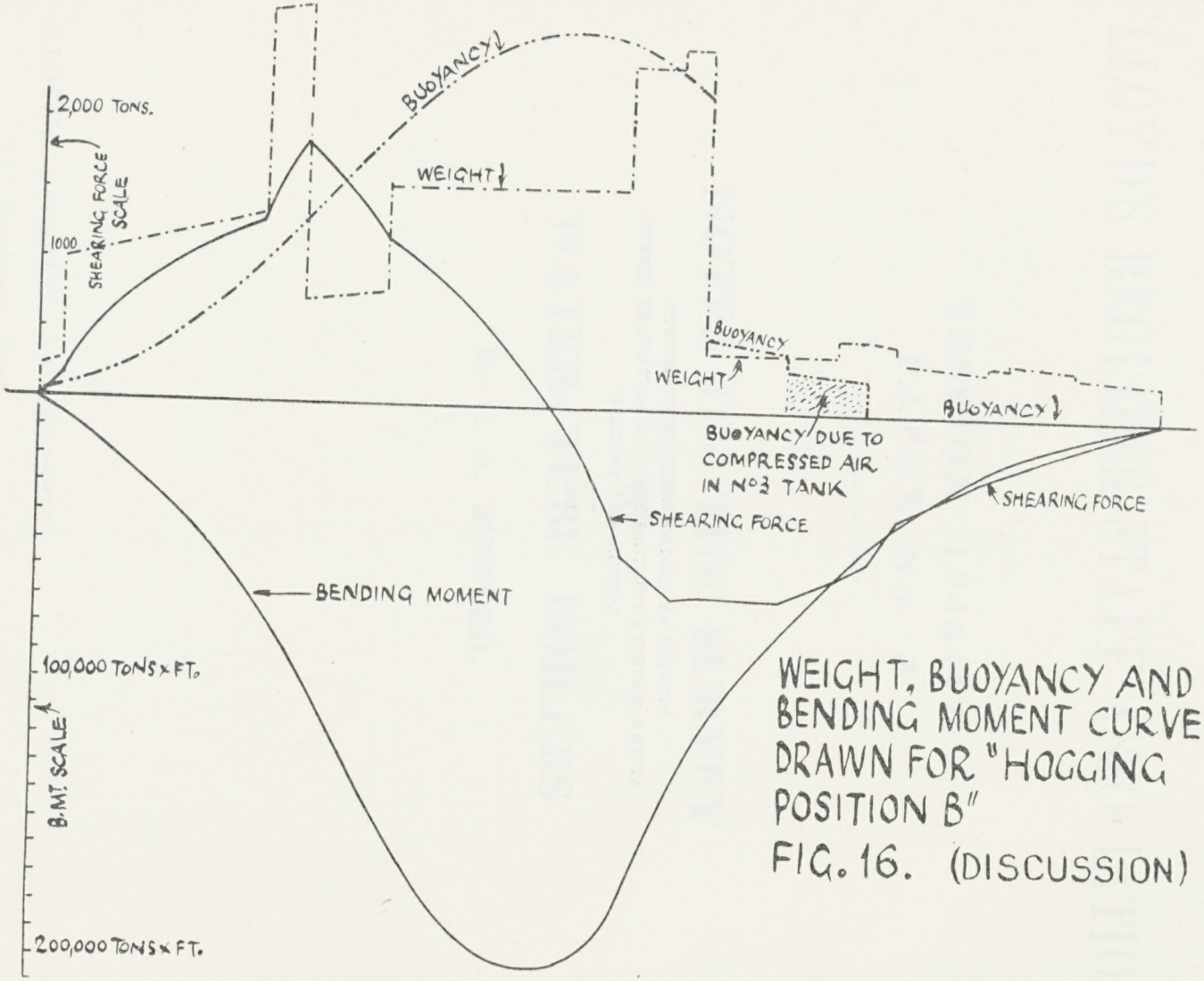
REINFORCED SECTION - Nº3 TANK
MODULUS = 17000 IN^2 x FEET.
FIG. 12e.

FIGS. 12a-e SHOWING AMOUNT OF STRUCTURE INCLUDED IN MODULUS CALCULATION.

(DISCUSSION)



WEIGHT, BUOYANCY AND
BENDING-MOMENT CURVES.
DRAWN FOR 'SAGGING POSITION A1'.
FIG. 15. (DISCUSSION)



WEIGHT, BUOYANCY AND BENDING MOMENT CURVES. DRAWN FOR "HOGGING POSITION B"
FIG. 16. (DISCUSSION)

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NOTES ON THE SURVEY OF WATER TUBE BOILERS

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The Author of this paper retains the right of subsequent publication, subject to the sanction of the Committee of Lloyd's Register. Any opinions expressed and statements made in this paper and in the subsequent discussion are those of the individuals.

NOTES ON THE SURVEY OF WATER TUBE BOILERS.

Introduction.

AT the commencement of the war, the number of vessels in the Merchant Navy utilising Water Tube Boilers as their means of steam generation was comparatively low.

In 1940, as the result of heavy losses, the position became indeed very serious, and the countries beyond the seas came to the rescue with the standard cargo and tanker vessels which, in many cases, were fitted with boilers of the water tube type.

The next problem to be faced was the lack of trained personnel to man these ships. In the initial stages the supply did meet the demand, but this was only short-lived and in consequence a very lean period followed, with its accompanying troubles.

Efforts were made to get more Engineers trained, but this was a slow process, partly due to mobilisation difficulties and lack of equipped training centres.

It is thought that, with the increasing size of Water Tube Boiler installations and the numbers of such boilers now being fitted in merchant ships, some notes on the survey of these boilers might be useful, not only as a paper, but in provoking a discussion, the outcome of which would be beneficial to all concerned.

The paper is not intended to cover design, but is rather a practical paper, explaining survey procedure, together with some of the defects likely to be met with and methods of repair employed.

Survey.

Water Tube Boilers may generally be divided into two main types, viz :—(1) Drums—Tubes—Drums and (2) Drums—Tubes—Headers, with a further sub-division of class (1), viz. :—large and small tube type, including forced and natural circulation. Each main integral part of the boiler is considered and the general survey procedure is discussed.

Tubes.

In class (1) all tubes are readily exposed by the removal of the drum doors, but in the case of class (2), e.g., Babcock & Wilcox Boiler, especially the larger units, the necessity to remove all caps is a question for consideration of the merits and demerits of each particular case, and is generally dependent on the quality of the feed water and the feed system employed. Perhaps this will offer some difficulty to the Surveyor, but to ask for every cap to be removed from a large installation is a tall order, besides being a costly one to the Owner, particularly with regard to the labour question.

In the case of small units, say up to 50,000 lb. per hour evaporation, the removal of all caps can be reasonably expected, whereas with units above this size, if the three bottom rows and approximately 33 per cent of the remainder are removed, with the understanding that an accurate record of removals be kept, then this should suffice. This would mean that the tubes in the bottom fire rows are surveyed annually whilst the remainder are seen once in three years. Of course, should the condition of the tubes examined be found to be other than efficient, then further caps should be removed to ascertain in more detail the general condition of the boiler. (The figures mentioned above are relevant to generating tubes as apart from downcomers and uprisers, all of which should be examined at each survey.)

Where circulators and inner tubes exist, they should all be removed and the main tubes cleaned and examined.

Straight tubes offer little difficulty in the way of survey because they can be sighted with the aid of a light at the opposite end, but in the case of bent tubes, e.g., uprisers, downcomers, Bailey wall tubes, a steel ball (slightly less in diameter than the bore of the tube) attached to

a line is passed through to ensure that there is neither heavy scale, deposit or obstruction (such things as pieces of waste, bolts, rivets have been removed, particularly at the initial survey, but the possibility cannot be overlooked at every survey).

Tube defects may be divided into three sections, viz. :—

(1) Overheating; (2) Internal corrosion;
(3) External corrosion.

Section 1.—Overheating.

This may be caused through deficiency of water (either local or general), internal deposit, grease or oil. Experience has shown that in many cases shortage of water has been the direct outcome of lack of attention by the operator, but mechanical failures play their part, especially when the plant is under full load conditions. Too much reliance is usually placed on the feed regulator, a mounting, which is invariably put into that class of "the leave well alone" and does not receive the regular attention it deserves.

The water capacity of the Water Tube Boiler as compared with the Scotch Boiler of equal evaporation is much smaller and in consequence any loss of water is rapidly felt throughout the boiler—the tubes invariably taking the brunt. When deficiencies occur, the water content in the tubes is replaced by steam—the heat transfer rate is reduced until eventually the tube becomes heated to approximately the temperature of the surrounding gases. The tube may bulge, rupture, hog, sag or be drawn from the drum or header with disastrous results, but still the inattentive operator goes on hoping that nothing will happen. Perhaps an old adage is applicable: "Eternal vigilance is the price of efficiency".

Local shortage of water may be caused by the formation of steam pockets due to defective circulation, a state sometimes brought about by the presence of some foreign body or article, an accumulation of sludge or scale; quick change from a low to a high rate of evaporation, local concentration of furnace gases (due sometimes to the poor state of the firebrick lining) and uneven firing. The results of the above defects are local and self-evident, usually taking the form of swelling or rupture.

The presence of a tiny film of oil or grease has an almost immediate effect and as it increases so the tube invariably hogs, as against sagging when a scale formation or heavy sludge is present.

Oil or grease will tend to line the upper wall of the tube and, being a poor conductor of heat, reduces the heat transfer rate at this part of the tube, and in consequence becomes hotter than the bottom, bringing about a state of unequal expansion, and the tube hogs. Similarly, with the presence of scale the tube will invariably take on a thin lining at the onset, but with loose sludge depositing, the bottom part of the tube generally becomes more thickly coated and causes the reverse cycle of events and the tube sags.

The danger attached to either hogging or sagging is the ultimate pulling out of the tube from the drum or header, and the extent to which these defects can be allowed to develop before replacement is only brought about by experience and careful recording of the history of the development. In nearly every unit, the fire row tubes will adjust themselves during the initial stages of the boiler's life and may give no further trouble, but a tube which persists in showing gradual increases at each examination definitely requires close attention and ultimate replacement. This defect, no matter how slight it may be, can be easily spotted when sighting the tubes with the aid of a lamp, but for record purposes the amount, of, say, above $\frac{3}{4}$ in.–1 in. (usually recorded by means of a line held in contact with the tube at its practical extremities) should be checked. The limiting factor in the safe margin before replacement is, of course, the length of the tube in question, but when a measurement of some 2 in. in the case of short tubes (say 12 ft.) is recorded then one can consider the useful life of the tube is at an end. Apart from the danger of pulling at the headers or drums, the sagged tube becomes a well for sludge and deposit, whilst the hogged tube encourages steam pockets at the summit and in both cases circulation is rendered less efficient.

Careful differentiation must be drawn between a tube which may appear bulged as against one which is blistered—the term blister is sometimes used erroneously and the following explanation will suffice to clear the point.

A tube is said to be bulged when both the inner and outer walls follow the same relative line of contour with continuity.

A tube is said to be blistered when a defect in the material, usually in the form of a lamination, causes a portion of the wall to abandon its homogenious state and part company, causing a local reduction in wall thickness.

Although in each case the outward appearance of a bulged and blistered tube may be similar, the difference can be easily detected by means of a discretionary hammer blow.

Before moving on to the next part of the paper, the Author would like to quote a few cases of special interest.

A boiler of the 4 Drum Type operating at a W.P. of 425 lb. per square inch with an evaporation of 80,000 lb. per hour developed a defect in the feed system whilst working under full load conditions and "lost the water". The unit was shut down and on examination it was found that the two banks of tubes next to the furnace had sagged to the extent of some 4 in. at the fire rows decreasing slightly on the remote rows to a minimum of some 2 in. in the back rows. The tubes were found to be slightly pulled from their landings in the drum, and the question arose, as it so often does, what to do in the interests of safety and economy. Detailed examination of the tubes revealed that no other apparent defects were present, and it was decided to re-expand all the tubes, record an accurate picture of the sagged condition, test the unit by hydraulic pressure and steam the boiler. This may seem contrary to the suggested figure of the maximum safe amount to allow before replacement, but the conditions prevailing at the time, viz., national crisis, coupled with the fact that the number of available spare tubes was only sufficient to tackle two rows. This part retube was found to be impracticable as the sagged condition of rows three and four was such that the new tubes could not be fitted.

It is of interest to record that this unit performed satisfactorily over a period of five years without further trouble, and records show that the tubes remained "permanently set" and without leakage of any kind.

Whilst this case can be placed under the heading "fortune favoured the brave", the next case, unfortunately, cannot be included under the same heading.

A W.T. boiler of an older type (where the tubes are in the same plane as the steam drum) working at a pressure of 180 lb. per square inch came under the compulsory eye of the B.O.T. through a fatal accident in which a tube in the fire row, 4 in. in diameter, ruptured over a distance of some 8 in.

All caps were removed from the headers and the tubes in the bottom row were found to be partially choked with scale and sludge.

The local water was known for its scale-forming property, and water treatment was an essential feature in the successful operation of this boiler. It appears that this treatment was either changed or overdone with the loosening of a quantity of scale and sludge. Under normal conditions of evaporation, the circulation is such that this loose scale and sludge is swept to the bottom of the headers and to the mudbox.

The boiler in question, being a component of a battery of boilers and whose duties necessitated various changes in load, was kept under banked fired condition. Under these conditions natural circulation throughout the boiler was arrested and almost brought to a standstill, which meant that the sludge and scale did not find its way to the mudbox, but began to build up in the lower rows, particularly the bottom row. The banked fired condition was maintained for several hours and then the boiler was put on full load. It was finally agreed that the heavy deposit in the tubes caused the overheating of the tubes, with the consequent disaster. It is of interest to note the observations of the counsel for the Owners of the boiler at the enquiry. He contended that the scale was deposited by virtue of the vibratory conditions present following the explosion—needless to say this was rejected.

The above case is an excellent example of why water tube boilers should never be kept under banked fired condition unless under conditions of extreme necessity (the quick steaming ability of most boilers being ample for service conditions).

Section 2.—Internal Corrosion.

Due to limitation of availability of internal surfaces of tubes, the detection and assessment of corrosion is indeed one of the most difficult parts of survey work.

Provided straight tubes are clean, no matter whether they be of small or large bore, their internal condition can be reasonably ascertained with the aid of some form of illumination at the opposite end. If after taking into careful consideration all the relevant factors and features of the tubes there still persists a doubt, then the only course is to recommend removal of a sample tube, or tubes, for dissection.

One of the most vulnerable points is at the bends of tubes, particularly if within the latitudes of the working water level of the boiler, e.g., downcomers, uprisers, &c., and the only indication one may get is the presence of oxide, in the form of small pieces at the bottom of the tubes, after the ball and line has been passed down.

The corrosion of tube ends, whether they be beaded or just expanded, is a matter for straightforward dealing inasmuch that when the extent of the corrosion creeps into the landing or seating portion of the tube, then renewal is invariably the decision, otherwise the resultant leakage will render the header or drum landings affected for the remainder of their life.

Section 3.—External Corrosion.

Perhaps one of the earliest of defects in new W.T. boilers is leakage at tube landings, and if allowed to develop can be the cause of excessive wastage and thinning of the tubes. It is usually at the most inaccessible places, e.g., between baffle walls and headers, where this occurs, and it should be insisted that facility should be afforded to carry out a satisfactory survey.

General smooth wastage of tubes cannot be readily detected, and calibration both diametrically or circumferentially where access is difficult, coupled with hammer testing, is the only indication.

Where generating tubes are used as means of support for the superheater, soot blowers, &c., it is always advisable to ascertain if all the clamps are "solid", otherwise the abrasive effect of a loose clamp can be quite severe.

A quite frequent occurrence, where superheaters are fitted, is the inclination for the superheater tubes to use the generating tubes as an additional means of support, no matter how well the clamps and hangers are disposed. The vibratory condition whilst steaming causes an abrasive action, with the result that flats of appreciable dimensions may be found at the point of contact. In one instance the Author can quote a reduction of 70–80 per cent of wall thickness through this cause.

Drums.

The steam drum of most units presents a very congested space to the Surveyor, and a thorough survey cannot be carried out unless the drum is made more accessible by the removal of deflection plates, dryers and scrubbers (if fitted) and feed troughs if of such construction as to render accessibility difficult.

With the advent of higher pressures the welded drum has practically superseded the riveted one, and in so doing has substantially reduced the possibility of one of the most serious of defects, viz., caustic embrittlement, the danger lying in the fact that it was not easily detected and, further, when it was detected, it invariably ended with the renewal of the drum.

Pitting along the water line is prevalent, but usually its small depth and lack of continuity renders it almost harmless, brushing and painting with protective paint being a preventative.

Perhaps one of the least noticed faults can be one of the most serious, if allowed any degree of scope, particularly with marine units in which the working conditions are so arduous.

The fault to which I refer is the lack of efficiency of the internal steam pipe, particular reference being made to its snugness to the drum. If I quote an actual experience it will help to make the point more pictorial.

The unit in question had an evaporation of some 200,000 lb. per hour at a working pressure of 1,400 lb. per square inch.

Repeated failure of superheater tubes (at the bends) was investigated and soluble carry over

was assessed as being the trouble. It was found that the internal steam pipe, or better described as a steam trough, had poorly fitted side and end plates with the consequence that the steam passing from the drum was highly saturated and a certain amount of priming had occurred.

This question of soluble carry over is indeed a question which has its roots deeply entwined in the chemistry of feed water, and no doubt a paper on this subject given by an industrial chemist would assist greatly in the differentiation of cases such as the one in question.

The cure in this case was effected by the fitting of cyclone dryers and scrubbers in series with the internal steam pipe.

Water Drums and Headers.

Water drums and headers usually afford a straightforward survey and the most likely defects being external wastage where in contact with brickwork or leakages from tube landings. Occasionally faulty caps give trouble, but this cannot be regarded as a defect but more as an operational fault. Whilst on this point it would be well to note that with multi-cap boilers, e.g., Babcock & Wilcox, it has been a recognised practice to subject a unit to a hydraulic test following each survey (usually to a pressure inside the working range) to ensure that all caps have been satisfactorily jointed.

The material used for cap joints may be of interest, more particularly with the higher pressures and temperatures. In the case of the above unit, ordinary thin jointing proved a failure, and eventually a stainless steel or monel metal covered asbestos gasket proved efficient, but costly (this has a reflection on the number of caps removed for survey).

Water Wall Headers and Tubes.

These carry out the triple duty of increasing evaporation, promoting circulation and, in certain types of boilers, prevent the clinker from adhering to the refractory lining of the furnace. Due to their close proximity to the furnace, the headers usually distort by "bowing" away from the fire and appear to settle at between half-inch and one inch, but this distortion cannot be regarded as being a danger but more of a permanent set.

An unusual case will be of interest. A Boiler (4-Drum type) of 80,000 lb. per hour evaporation and working pressure 425 lb. per square inch fitted with water wall headers along either side of the moving grate, of scantlings 7 in. × 6 in. × $\frac{7}{8}$ in. thick. After a period of eight years' service, the exposed faces of these headers developed a series of vertical cracks commencing at the bottom edge and extending some three inches in length in the transverse plane. Although no leakage was noticed, it was decided to remove the headers (quite a simple task of flame-cutting the four connecting pipes) for more detailed examination. The whole of the exposed face was affected by hundreds of fine cracks extending, as already stated, some three to four inches but whose depth could not be readily ascertained.

New headers could not be obtained without considerable delay, and the fact that the factor of safety was high, it was decided to machine a wedge piece from the affected face from nothing to $\frac{3}{8}$ in. at the corner, to include the majority of the cracks. A number of cracks remained after this operation—these were veed and welded. The unit steamed satisfactorily for several years. It was found that all the remaining boilers of the same age were similarly affected and the contributory cause may have been excess clearance between the moving grate and headers creating a rush of cool air with resultant contraction stresses. Maybe they were fatigue cracks as the metal which was machined showed some signs of this defect.

Water wall headers and tubes should be exposed at the lower part, especially where in contact with brickwork, as external corrosion can be very active at these parts.

Superheaters.

Drum Type.—A typical type is the 4-Drum Boiler, others being very similar. The passage of the steam through the drum is contra flow and the baffles fitted to ensure this circulation must be removed at survey time.

No doubt quite a number of us has carried out that well-known experiment in the laboratory of passing steam over heated iron filings and producing hydrogen gas and iron oxide. This is just what happens in most superheaters,

especially at the inlet ends, where the corrosion is quite noticeable, more particularly in the header type, and it is the tube ends which appear to suffer most.

One case comes to mind; the drum ends became pitted at the root of the flanging, eventually becoming continuous grooving, with the result that renewal of ends was necessary. This operation was carried out on site, the drums being of riveted construction and the new ends being of the flat type and not flanged for the manhole as previously.

The defect mostly associated with the outlet end is the hair cracking, radiating from the drain opening, and may be attributed to globules of water having a local cooling effect on the surface layers (the action of these globules is best illustrated when a kettle boils over on a hot stove).

Header Type.—One of the most important points to watch in the survey of this part is that the division wall in the inlet headers is sound and its draining facility correct. In the earlier days it was quite a common error to find the small hole or groove in the division plate at the top instead of the bottom; perhaps the designer has realised the risk of this occurring by insisting on a hole on each side of the plate, viz., top and bottom, the by-passing of a small amount of steam being negligible as compared with the efficient drainage of the header, which, by the way, should always take place in the direction of the flow of steam, and not against it.

The corrosion of tube ends is an almost expected defect, and the danger arises from leakage caused by their loss of "bite" in the header. If a number is affected the best repair is to crop the whole of the nest, anneal the ends and refit.

Desuperheaters.

In the earlier days it was found that with installations having frequent fluctuations of load, no means were provided for controlling the superheat and the superheater often suffered from the effects of overheating.

Also the use of superheated steam in auxiliary machinery was found to be unsuitable, mainly due to lubrication difficulties brought about by temperature conditions.

The desuperheater was originally introduced in rather crude form, consisting of a vessel fitted with a controlled jet of feed water connected in the line requiring saturated steam. This proved far from satisfactory because of the vessel's failure to withstand the operating conditions—cracks frequently developed at the inlet end.

In marine practice, where space is often limited, it is not always possible to have sufficient boilers installed to supply the varying requirements of saturated steam. The present practice is to pass superheated steam through pipes (sometimes gilled) fitted inside the steam drum and discharge steam at approximately the temperature of the drum but of a high dryness fraction, thereby obtaining high efficiency throughout the auxiliary system without the high temperature complex. In effect, the steam drum becomes a heat exchanger.

The only disadvantage, so far as the Surveyor is concerned, is that the steam drum becomes more congested than ever, making survey work more hazardous.

Economisers.

Economisers of various forms have been used since the early days of steam, but as working pressures and temperatures have risen, so the desire to effect economy has become of paramount importance due to the increase in available waste heat.

In modern practice the type most common is the steel tube with gilled cast iron fins shrunk on, the latter offering increased heating surface together with protection of the tube against corrosion. The tubes are expanded in small return headers and we have in effect a contra-flow type of heater.

The soft corrosion experienced with the cast iron tubes of the older type of economiser is conspicuous by its absence, and very little in the way of defects can be quoted.

The removal of one or two caps per row is recognised as being sufficient to enable a Surveyor to gauge the general condition.

Mountings.

The additional fitting required for a water tube boiler as compared with a Scotch boiler, viz., Automatic Feed Regulator, is one which requires special care and attention because the whole successful operation of the plant is so dependent on its function.

The recognised practice of setting superheater safety valves at approximately ten per cent below the main valves is brought about mainly with a view to ensuring that the superheater is circulated with "cooling" steam at all times, and further, the main valves are kept in better trim than they would be if designed to lift at the slightest opportunity, all due regard being given to the safety of the plant.

Blow down valves are usually of the parallel slide type, and it is as well to make a special note of examining these after overhaul to ensure that the valves cannot over-run the body—the Author having experienced the case of a whole unit being shut down due to an attendant opening the valve full bore and the discs jumping out of the body.

Defective Material and Bad Workmanship.

The completeness of Lloyd's Register survey during construction is mainly responsible for keeping the number of defects, attributable to the above, within negligible limits. Each case requires expert analysis before final conclusions are stated.

The case of the blistered tube, already mentioned, can be regarded as a "latent" defect and beyond the scope of visual survey at the tube works.

When monotony arises during stages of construction, the evil of bad workmanship becomes prominent and the fitting and preparation of tubes offers most scope.

Briefly, they present:—

(1) Tubes cut to incorrect length.
(2) Insufficient rounding of tube ends.
(3) Inefficient annealing of the tube ends.
(4) Selection of "minus" tolerance tubes for "plus" holes.
(5) Ragged landings in drums or headers.

In all water tube boilers the importance of correct alignment of the drums or headers before fitting the tubes cannot be overlooked.

It is an acknowledged fact that it is indeed a physical impossibility for a Surveyor to see every detail and witness every phase of the construction, and some integrity has to be assumed on behalf of the man at the bench. However, it must always be remembered that the final responsibility for accepting the boiler for service rests with the Surveyor.

In conclusion, it is my sincere hope that these brief notes will provoke an informative discussion drawn from the experiences of other colleagues in the survey of W.T. Boilers.

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DISCUSSION AND AUTHOR'S REPLIES

on

Mr. C. A. Bedford's Paper

"NOTES ON THE SURVEY OF WATER TUBE BOILERS"

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Discussion on Mr. C. A. Bedford's Paper

"NOTES ON THE SURVEY OF WATER TUBE BOILERS"

MR. T. GIBBESON.

Caps.—With regard to caps and the number to be removed, I agree with Mr. Bedford that for the larger boiler (land installations) 33 per cent. of the first three rows is quite a reasonable figure to ask. For marine installations, which are much smaller, I certainly think that all the tube ends should be exposed. Experience has shown that it is not sufficient to assume that because a certain batch have been exposed, and been found good, that the remainder will also be in good condition. Due to the devious paths the flue gases take, certain tubes are exposed to higher temperatures and perform greater evaporative duties than others, hence more scale and sludge are likely to collect in these. I agree with Mr. Bedford that the caps should always be removed from the three bottom fire rows, as these have the most work to do. The tubes, after all, are the main arteries of the boiler and should have special attention. Caps should also be examined; nuts and bolts may have wasted threads or clamps may be broken or twisted. If caps have been leaking, then look for wastage of joint facings.

Sighting of Tubes.—I agree with Mr. Bedford that the "lamp at one end method" for sighting tubes is usually adopted. It shows up hogging and sagging very well. I prefer a torch with a good beam shone in from each end of the tube. Pitting should be looked for. Local pitting here and there is not considered serious, but if it is general along the tubes and deep, then action should be taken.

Bailey Wall Tubes.—The ball and line method is very good for ascertaining if there is any obstruction in the tube, but not much use for determining the degree of corrosion, if any. A little scale expelled from the tube does not tell one very much.

Another point is to see that all scale has been removed from the tubes and that they have been well brushed. It is astonishing how a small pit hole in a tube seems to look like a deep crevice when a light is shone in. I agree with Mr. Bedford, if at all doubtful get one or two out for examination.

Tools for Cleaning Tubes.—It is quite a good thing to examine these and if they are mechanically operated to see that they are not too severe in their action. There have been cases of tubes being cut, split or made oval due to tools being improperly handled.

Fire Side.—I agree with Mr. Bedford that a 2 in. sag on a 12 ft. long tube should be about the maximum allowed. I usually test with a lath and check up with previous records. The tubes may have come down in the early life of the boiler and have now got into a "set position." I agree a sagged tube forming a loop is bad and should be removed. I would like to ask Mr. Bedford if he has had any experience of an internal blister which is stated to be caused through a gas bubble being trapped in the plate when it is rolled, and continuous heating of the tube under working conditions expands the bubble, causing an inward bulge or blister. Grooving or wastage, due to damp soot, at the ends where the tubes enter the headers on the fire side should be looked for.

In the example Mr. Bedford quotes where, through loss of water, the fire row of tubes sagged four inches, it would be interesting to

know the amount the tube was left projecting through the drum for expansion purposes, and if the tube ends were bell-mouthed.

Mud Drums.—It is advisable to look for external wastage of mud drums at the bottom, due to dampers and leakage.

External Corrosion of Tubes.—If you suspect wastage to such an extent that you think the tubes should be calipered, then you should not hesitate to take the defective tubes out. The tubes would have to be thoroughly cleaned before a caliper reading could be sufficiently accurate. I should imagine it would take much experience and a good ear to detect a thin tube by hammer testing.

Drum Examination.—I agree with Mr. Bedford that this is extremely difficult, especially with all the latest devices fitted inside. Usually no effort is made to remove any of these to enable the Surveyor to make a more thorough examination, and he has to wend his way in and out as best he can. Lagging should be removed from longitudinal and circumferential seams if drum is of riveted construction. Landings should be examined and rivet heads hammered.

Mountings.—I agree with Mr. Bedford that the F.W. regulator should have special attention.

Superheater.—If the superheater can be isolated from the boiler, it is necessary to see that it has its own safety valve and that it is in good order. Mr. Bedford mentions hair cracks round the drain hole. I think these could be avoided if the nozzle ends were beaded over or welded flush and did not project through into the drum so that the water could be completely drained away.

MR. W. NICHOLSON.

After noting the author's remarks on Tubes, I feel it might be emphasised that internal corrosion is *not* confined to the bottom rows of tubes in sectional header type boilers. Serious internal corrosion is not infrequently found in the top rows of tubes—especially at the front end in cross-tube type boilers, such as the B & W type, and in the short front nipples attaching the headers to the drum. Trouble is occasionally found in the top return tubes between the back headers and the steam drum.

External wastage other than that caused by leakage at tube expansions should be looked for in the furnace tubes. Severe thinning of these tubes frequently occurs due to the erosive and corrosive action of gritty fuel and fuel having a high sulphur content, especially in coal-burning jobs. Defective tubes are best located with the aid of calipers and by hammer testing. Soot blowers occasionally cause severe local erosion of tubes. In one group of sectional header boilers with blowers fitted in the Scotch furnace between the second and third row of tubes, tubes quarter-inch thick were frequently cut locally to paper thickness after less than two years' service. These defects had to be located by the sense of touch. Repeated efforts to readjust the blower tubes were not successful.

Internal and external corrosion of header joint faces should also be looked for.

Superheaters.—The author appears to suggest that the corrosion of tube ends and headers in the saturated or inlet end of superheater drums or headers is due to the dissociation of steam into hydrogen and oxygen. I am of the opinion that such corrosion is caused by air and oxygen carried over with the steam from the boiler drum, due to inefficient deaeration of the feed water. Steam would tend to dissociate into hydrogen and oxygen only at relatively high temperatures, such as would be experienced with serious overheating of superheater tubes at well over 900° F.

Economisers.—The adoption of steel tube economisers fitted with external cast iron gills or fins is hardly universal, and nests of plain or bare tubes are often used, especially with La Mont and forced circulation type boilers. If the temperature of the feed water is allowed to get below the dew point of the flue gases for any length of time, considerable external corrosion may result.

Where the deaeration of feed water is poor or reciprocating pumps are used with inefficient speed regulation, internal corrosion might be expected in the economisers. In one forced circulation boiler, repeated tube failures occurred in the economiser, while the furnace and superheater tubes were comparatively trouble free.

With forced circulation type boilers, having tube nests which are often inaccessible, would the author state his views on the application of hydraulic tests at each survey, say, to one-and-a-half times W.P.; and does he consider the survey of the circulating pump should be an annual affair, since failure of that pump would tend to shut down the boiler?

MR. A. C. CHAMPNESS.

In Section I Mr. Bedford quotes the usual causes of overheating of tubes, each of which it is possible to determine. But cases have occurred of front row evaporator or water screen tubes seriously overheated in the absence of any evidence such as scale, oil or loss of water.

These cases have been traced to defective circulation due to forcing the boiler, and have been accompanied by superheater trouble.

A particular case was that of a 150,000lb./hour 3 in. drum boiler in which distortion of a number of tubes occurred, and in the absence of any satisfactory explanation, Pitot tube experiments were carried out in the downcomers to the side screens—4 in. tubes, if I remember rightly.

As a result it was established that up to a certain figure of evaporation normal circulation was obtained, but that above that figure the circulation in the downcomers was indeterminate.

Chronic superheater trouble due to carry-over, in spite of steam separators, was a feature of the case, with the inference that the boiler had been forced. When, therefore, a Surveyor is stumped for an obvious cause of tube overheating, examination of superheater condition and renewal records may provide a clue.

In the same section Mr. Bedford has been bold enough to suggest a limiting figure for axial distortion of overheated tubes. Maybe he was fishing for comment, and I shall bite because I have had that problem. When in the case of a distorted tube, leakage occurs at the drum or header as a result, the recommendation is obvious; but when the tube ends have not been disturbed, and the inclination of the tube is sufficiently steep to preclude sludge pockets, an answer to the Superintendent who says "Why two?" can be provided by metallurgical examination.

It is remarkable how much a tube can distort and still remain structurally normal, but a micrograph of a section of tube wall that shows decarburisation or an overheated structure will settle any doubts. In this connection it should be remembered that, whereas in land practice the drum-and-tube type of boiler is generally suspended from stools attached to the upper drums, marine practice is to support the whole assembly upon stools at the lower drums, when any assessment of permissible tube deflection must take into account the function of the tubes as supports for the upper drum or drums.

On page 3 definitions of "bulging" and "blistering" are given, but the particular blister defined is clearly a lamination—a rare case in a solid drawn tube. There have been many cases of blistering where, to quote Mr. Bedford, "both the inner and outer walls follow the same relative line of contour with continuity."

Such blisters may be due to flame impingement, or, when located at bends, to sludge deposits, and since they are generally decarburised and thinned at their crowns, they mean rejection of the tubes.

There is a reason for this distinction between "blistering" and "bulging." Local bulging, that is, a slight increase in diameter over part of the tube length, is by no means rare in the fire rows of water tube boilers that have seen considerable service. If it is viewed as a creep function over short periods of time on irregular or heavy duty no structural deterioration need necessarily be anticipated, and I have confirmed this point in a number of cases.

But a "blister," that is to say, a small local swelling that may be no larger than a half-crown, is always suspect for potential trouble, if only on account of steam-pocket formation.

As a general remark on the tube troubles, I wonder if Mr. Bedford will agree with me that "ringing" tubes with a hammer is a most inconclusive business, mainly on account of vibration over the whole unsupported length.

In column 2 of the same page a fatal accident case is described, and attributed to banked fires. The "banked fires" condition, although unavoidable on occasions, is not a happy one for any

type of boiler, but it is considered that the case in point contributes only indirectly to the general condemnation of banking fires.

The tube failure was directly attributable to sludge deposits resulting from an overdose of feed treatment, and there is no evidence mentioned to show that the tube would have failed in the absence of that sludge, or that it would not have failed—as many have done in similar circumstances—under normal firing conditions. This comment is made more in a spirit of enquiry than of criticism, without full knowledge of all the facts of the case.

Caustic embrittlement is merely touched upon on page 4, and perhaps Mr. Bedford will enlarge upon this subject in his written replies. If so, and when mentioning the usual evidence, brittle rivets, black magnetic-oxide deposits, and so forth, he will no doubt stress the importance of looking for evidence of repeated caulking of seams or rivets.

On page 5 a case of water-wall header cracks is quoted, and the possibility of their being fatigue cracks is mentioned. This is an interesting suggestion, as one is not accustomed to associate fatigue conditions with headers of small, stiff section. Mr. Bedford probably knows more details of this case than appear in the paper, but from the facts given one might ascribe the cracks to thermal stresses in a corrosive environment.

One notes that the main requirement from the survey angle, putting the job right, was carried out satisfactorily, and it would be of interest if Mr. Bedford would tell us whether or not the header was heat treated after the welding repair.

During the forging of the ends of solid drums, tool marks sometimes give the appearance of surface wastage on the water side in way of the radius. The illusion was made complete in one case I remember where the surface irregularities had been doctored with a caulking tool producing ideal scale-free conditions for subsequent corrosion.

Another point concerns mud-drum surface wastage due to high sulphur-content combustion products. The wastage took the form of local pits at the edges of the tube holes on the fire side of a mud-drum connected to the front steam drum by an approximately vertical bank of tubes.

It appears that when the boiler was shut down the products condensed on the lower parts of those tubes, the coolest part of the tube assembly, ran down the tubes and collected rather like candle grease round the tube neck, where they proved actively corrosive.

Since soot blowers rarely reach the extreme ends of tube banks, these locations are worth a little special attention at surveys.

I would also ask Mr. Bedford if he has come across isolated pits, in some cases only one or two in each tube, of quite large diameter and tending to complete perforation on the water side of inclined tubes in Babcock boilers. These are an insidious type of defect, as they may be, as in my own case, covered by scale and only betrayed by the scale being slightly raised in the form of a small blister.

If so, to what would Mr. Bedford attribute such defects in otherwise sound tubes?

Finally, I would like to mention a specific case of peculiar interest concerning a Prudhon-Capus boiler, a hybrid type of dry-back Scotch boiler with a water-walled combustion chamber back; essentially a water tube boiler. The vessel had two boilers, and the pipes connecting the water gauges of these German-built boilers were flanged and welded direct to the shells. When the usual breast cocks were fitted to meet the Rule requirements the inboard lower cocks were fitted at the usual height, and the outboard lower cocks, on account of the proximity of the side bunkers, were fitted very low down on the shells. On the vessel's arrival in London, the Chief Engineer stated that although the inboard gauges worked perfectly it had been impossible to maintain a water level in the outboard glasses when steam was raised. In fact, he stated, there seemed to be "water running down the glass all the time." The usual tests were applied and a complete examination showed the gauge glass fittings to be in good order.

The outboard lower cocks were removed and fitted at the same height as the inboard ones, with the result that all the gauges then functioned normally.

The interesting conclusion to be drawn is that under the particular circumstances of this type of boiler, the location of a lower breast cock near the bottom of the boiler, with the consequent long length of exposed piping, caused the arrangement to function as a downcomer, probably with good effect on the circulation of the boiler.

It should be mentioned that careful blowing of the glasses precluded any possibility of obstruction due to sludge or other solid matter.

MR. P. T. BROWN.

It is fifty odd years since Messageries Maritimes fitted water tube boilers (Belleville) into some of their ships and over fifty years since the Royal Navy followed that lead. Before the South African war H.M. battleships and cruisers were fitted with Belleville, Niclause, Babcock or Durr boilers—the first being the most general—whilst in destroyers a number of types were tried out with varying success. Amongst those I remember were the Thornycroft "Speedy" and "Daring" types, Yarrow, Normand, Blechynden, Reed and White-Foster. All had good and bad features but it was the latter which were the subject of a nation-wide controversy at the end of the last century which ended in the Government appointing a Committee, on which the Society had the honour of being represented, to investigate the matter. The decision favoured the water tube boiler, although making a compromise that in the case of the largest vessels one boiler room would be fitted with Scotch boilers for use in "easy-steaming." It was also decided to standardise the types. The Babcock & Wilcox boiler was adopted as the large tube type for battleships and cruisers and the Yarrow as the small tube type for destroyers.

The author refers to the removal of caps in Babcock & Wilcox boilers and suggests the three bottom rows and one third of the remainder. This is fair, reasonable and practicable, but the Surveyor must be guided by circumstance. The work of opening out and closing water tube boilers being one of the objections to their use, a conciliatory approach is needed when stating requirements for survey. If all caps are removed and no help given in the way of removing baffles and other fittings which impede the interior examination of drums (one of my own experiences) the visible preparation is mere eye-wash.

Mr. Bedford refers to blistered tubes. Such are, of course, revelations of inherent defects in material which it is feared the prescribed tests can only fortuitously reveal. However, the incidence of this defect is not appreciable, due to the fact that only good steel will stand up to the manufacturing process.

Reference is made to hogging and sagging of tubes and an illustration given. The author does not give the diameter or length of the tubes, but I do not think any undue risk was taken. Supposing the length to have been 12 ft. the increase by 4 in. sag would only be about 3 in., an amount which a solid drawn tube of 24/28 ton steel would easily accommodate. In this context we should remember "Pluto" and how that pipe line was laid, used and raised.

Mr. Bedford rightly draws attention to the Automatic Feed Water Regulator. This is the most important feature of a water tube boiler, and it must be kept in perfect condition; in operation, failure of this mounting is the most frequent cause of trouble. Water quality is most important, and it would be better if only distilled water were used. Make up must be with distilled water. This matter is so important that it would be a good thing to test the main and auxiliary (if any) condensers at each boiler survey.

MR. H. P. SOUTHWELL.

Water tube boilers have now come to stay, and new types and improvements in the older designs must be closely followed by all who have to examine them. I would recommend any Surveyor who is confronted with a water tube boiler with which he is not absolutely familiar to spend a few moments looking over the plans he will find on board before going down below.

I would also like to stress the necessity of examining the furnace casings and the refractory linings in way. Failures of brickwork and casings can affect the boiler efficiency just as

certainly as can other and more technical troubles. This refers particularly to some of the more modern high pressure boilers.

A slight leakage past the brickwork will quickly buckle the casing and make a reduction in furnace temperature compulsory.

Such a failure becomes very rapidly worse, too, and has more than once in my experience made it necessary to shut down a boiler completely. In each case the shut-down was necessary not only because the casing was burned, but because the buckling had sprung joints and seams, and the stokehold and engine room were becoming full of fumes.

It should always be borne in mind when surveying these boilers that much higher temperatures are generally being dealt with, and faults and troubles are not so easily located as they are in Scotch boilers. In other words: The less you can see the more there is to fear.

MR. F. BROOKE SMITH.

The author appears to have little faith in feed regulators, many of which to-day have proved to be very reliable when under adverse conditions, and it is not considered that there is any danger in placing full reliance on the feed regulator, with, of course, normal watch keeping attention. It is agreed that they may be efficiently overhauled periodically, preferably by the maker's representative.

Local shortage of water is stated to be due to many causes, the last of which is given as uneven firing. Does the author visualise water tube boilers being hand coal fired? This would be something new to the writer.

The author's remarks re hogging and sagging have been read with interest, especially the limiting factor of, say, 2 in. in a tube length of about 12 ft. This seems somewhat excessive, and it would be of value to learn if tubes distorted to approximately this amount have continued without being renewed.

The point in connection with a tube being either blistered or bulged is not clearly understood. If the appearance of a tube is such that it is one or the other, then surely it should be renewed, without bothering to ascertain which of the two it happens to be.

It is of interest to learn that a tube can blister due to lamination of the material, and perhaps the author will confirm if he has encountered this happening.

Two cases of special interest are quoted in the paper. The first is well worth noting in view of the damage caused through "lost water," the condition of the tubes and the fact that the boilers performed satisfactorily over a period of five years after the minimum amount of repairs to keep it tight had been effected. Some Surveyor at a future date may be pleased to keep this in mind when faced with conditions somewhat similar, especially if in a foreign port, where no spares are obtainable, and it is desired to get the ship home.

Dealing with external corrosion, reference is made to general smooth wastage, which seems a sinister thing as access to so many of the tubes is most difficult. I will refer to this again later.

The author states that the adoption of the welded drum instead of the riveted drum with the advent of higher pressure has substantially reduced the possibility of that often talked of, but rarely encountered, defect " caustic embrittlement." With high pressure one assumes that the boiler is filled with distilled water and the make up is also distilled, if not double-distilled, and the feed is a closed circuit. If this is the case, as is believed, what is the object or necessity for introducing into the boilers any agent which is of a caustic nature and able to give rise to embrittlement?

The author gives many hints regarding the surveying of water tube boilers from which the writer, for one, has gathered useful information. The question of removal of caps frequently presents difficulties, and further difficulties arise in the keeping of accurate records of the removals. It is agreed that the removal of a number of caps to enable the Surveyor to form his own judgment is commendable, but, as stated earlier in this contribution, access to many of the tubes, and other parts, is most difficult, and an opinion by the author would be welcome as to

whether or not water tube boilers should be periodically tested with hydraulic pressure greater than the working pressure. It is thought that this would relieve any anxiety felt by the Surveyor that those parts not easily accessible were efficient.

One last thought: oil fired boilers, any type, require that steam smothering arrangements be fitted. In water tube boilers, with their small steam space, one wonders how long in the case of a serious outbreak of fire in the engine or boiler room the steam supply would remain efficient for the purpose of smothering the fire, particularly in view of the fact that the oil fuel is shut off as a precautionary measure.

MR. L. R. HORNE.

The author mentions in Section 3 the wastage of tubes caused by leakage. Leakage may also lead to wastage of the tube plate. In one case grooves about one thirty-second in. deep were found in several adjacent tube holes. This left the rather unsatisfactory alternatives of either welding up the grooves without stress relieving or enlarging the holes and thereby weakening the drum. The former was chosen.

Later on in this section the author refers to caustic embrittlement. Has he any detailed information to give us? Little has been heard of this subject in recent years, and I think Surveyors generally are hopeful that the chemical conditions in which it took place are now allowed to occur only very rarely.

With regard to the adjustment of safety valves on the saturated and superheated sections of a boiler, I would suggest that the difference in pressure to which they are adjusted should be the same as that which is maintained under full steaming conditions. This will ensure that in the extreme case when the engines are suddenly stopped and the boilers are "kept under full firing conditions" the valves will operate with maximum efficiency.

MR. N. CHAMBERS.

Referring to the hogging and sagging of tubes due to overheating, Mr. Bedford implies that if a tube be found hogged it has been overheated by the presence of oil or grease, and if it be sagged the sagging is caused by sludge or scale at the lower part of the tube. This is not always true as excessive or uneven firing can cause tubes to hog or sag without the presence of scale or oil. Tubes sometimes distort sideways, and it may be that the direction in which they move is influenced by stresses set up when they are expanded into the drums or headers.

In dealing with the examination of tubes, Mr. Bedford omits to mention the possibility of finding fine cracks externally, especially where the tubes appear to have been overheated.

Mr. Bedford states that water tube boilers should never be kept under banked fire conditions, but I do not see why trouble should be experienced if the boiler is clean, has suitable feed water, and is properly fired. The primary cause of the accident he quotes seems to have been that the boiler was dirty and not that it was kept under banked fire conditions.

MR. C. N. STUART.

Special attention should be paid to the securing of all the internal fitments of the steam drum, as I have found that the severe vibration which Water Tube Boilers suffer from under certain conditions causes bolts and nuts to work slack, and these are liable to drop down inside the tubes and cause stoppage and local heating. One way to overcome this is to spot weld all nuts to the bolts or brackets.

Although it may be possible to sight the tubes, after cleaning and polishing with rotating wire brushes, this cleaning only tends to polish the oxide scale formed inside the tubes, particularly if apexior is extensively used and the extent or depth of the corrosion of the tube is difficult to assess. If traces of this corrosion are seen, one of the worst tubes should be cut out to ascertain the depth of the corrosion, as I have known cases where the sighting of the tubes would not lead one to think that there was any excessive action, but when tubes were cut out and sectioned the pitting was as much as 60 per cent. of the tube thickness.

MR. ALEX. EWING.

I am glad to note that Mr. Bedford puts feed regulators in the first paragraph of Section I. The importance of the regular overhaul of feed regulators has to be driven home.

In two cases in this port during the last three years, the tubes have been found to be melted and hanging like icicles. These boilers must have been practically empty for there were no reports of explosion and no casualties.

The water tube boiler has proved so reliable ashore that we must attribute the troubles experienced afloat to lack of experience of the men in charge and the difficulty of keeping clear of salt water.

Pure feed water is absolutely necessary, and to ensure this, condensers must be perfect and distilling plant must have ample capacity to deal with abnormal losses which occasionally require to be made up.

As boilers have to be filled at any port where the water may be unsuitable, sufficient distilled water should be stored to fill the boilers after cleaning.

The author's remarks regarding the effect of lying under banked fires stopping circulation, and causing local steam pockets when rate of evaporation is suddenly increased, should be impressed on the personnel of water tube boiler plant.

Regarding external corrosion of tubes the worst examples of this I have encountered have been wastage of the short nipples connecting vertical headers to the mud drum.

In fitting tubes either in new or repair work, it is essential that the tube end should be axially true with the hole in the header or drum, otherwise the metal will be distressed in expanding. Swelled ends of tubes are the worst offenders in this respect, as the usual method of swelling is somewhat crude.

MR. R. RENNIE.

The author's definition of the distinction between bulging and blistering and his explanation that hogging is due to oil whilst sagging is due to scale deposits is well worth noting.

Here in Vancouver a fair amount of experience has been obtained with the sinuous header type oil fired boilers of the Canadian built 10,000 tonners based on this port. These boilers were built locally and have all-welded steam drums.

Many of the boilers are now between three and four years old and the only trouble so far experienced is with the fire row of 4-inch generating tubes, except for one classic case when a boiler was destroyed completely due to loss of water.

There have been several cases of split or laminated tubes. A number of instances of bulged tubes, some quite serious, have occurred here due to scale or sludge deposits but other cases have also occurred of deformation of 4-inch fire row tubes, chiefly sagging, usually associated with leaky tube ends. This deformation has been put down to oil, scale, cement wash from feed tanks, and other impurities in the boilers. Occasionally it has been found that the cast iron baffles were not sufficiently free tending to deflect tubes out of the straight.

The 4-inch tubes being nearer the fire tend to expand a greater amount than the 2-inch tubes above. The movement of the back headers not being sufficient to accommodate same, the fire row tubes may spring slightly out of shape but after re-expanding, if necessary, they should give little further trouble. The difference in expansion of the fire row and other tubes is accentuated if heavy soot deposits are allowed to form on the 2-inch tubes, causing retardation of the flue gases. Under operating conditions the soot blowers should be used at intervals of 12 hours or less and used properly so that the tubes are swept in correct sequence.

Deformation of tubes is also attributable to improper firing causing heavy soot deposits or direct impingement of the flame on the fire row tubes leading to local overheating, especially in way of soot deposits or baffles. It may also be caused by poor circulation, by too rapid blowing down or cooling off of boilers.

When renewing tubes, the ends should be annealed and should project through the holes at least $\frac{3}{16}$ inch and should be slightly belled

to reduce possibility of pulling out. If oil is used when expanding tubes it should be carefully removed by kerosene or, if necessary, by boiling out.

In general the importance of deformation of fire row tubes is exaggerated. The tendency here is to renew bent tubes at far less than the author's limit of 2 inches for a 12-foot tube. Unless there is side deflection tending to contact of adjacent tubes or interference with the flow of gases through the tube bank, deflections of 1 inch or so should be acceptable if tube ends are tight. After all, in many types of boilers, bent tubes are a feature of the design.

Careful inspection of sliding feet should be made at surveys to ensure that these are greased and free to move. Brickwork, if defective, should be made good, also packing between headers, and the tightness of casings, doors, &c., should have attention.

The feed regulator should be examined and it is usually worth while checking the condition of the filtering arrangements. The advisability of cutting down internal lubrication of cylinders to a minimum, avoidance of the use of the feed injector which has no filter, maintaining tight condensers and so on, by the Ship's Engineers, will tend to promote better operation of water tube boilers, especially if distilled water only is used and a good system of feed water treatment adopted.

MR. GLEN J. THOMAS.

As pointed out in the paper, at least some of the defects encountered during the periodical surveys arise from defective workmanship.

Mr. Bedford mentions leakage at tube landings in new boilers which may or may not be due to defective workmanship. We do, of course, find an occasional tube hole in the finished drum which is not one hundred per cent., in most instances due to damage by the reamer, but whereas a circumferential tear may be relatively unimportant if the rolling area damaged is not excessive, an axial score, even if slight, must be considered from the point of view of tube tightness. If the score is not too deep the hole can be enlarged a few thousands, and in some cases it has been necessary to fit a special tube with an enlarged end. Defects in tube holes have been dealt with by electric welding and reboring, but this method does not appear to meet with universal approval, although for an isolated tube hole I do not think there are really good grounds for objection. However, repairs of this nature would, to a new boiler, require to be submitted if agreed to by the Owners.

I have also seen considerable damage done to tube holes when removing for renewal, damage which is, I think, unnecessary if proper tools, such as spigoted drivers and cutters are employed and reasonable care taken.

In witnessing a hydraulic test in a new boiler a few tubes may show a slight dampness at the full test pressure but I do not think this is an indication of bad workmanship. It may be taken as an indication that the tubes generally are not over expanded and a slight rolling of a few tubes after the test is not a serious matter.

Damage to tube ends through excessive belling, that is usually a split, should not be found in new boilers as the examination of tube ends on completion of tubing usually receives the Surveyor's most careful attention, each tube end in steam and water drum and headers, if fitted, being individually examined. This is the most arduous task of the survey, particularly in the case of water drums of small diameter. However, a bad tube end should rarely be found, the removal of one tube in a finished boiler sometimes entailing the removal of quite a number for access, which, as can be imagined, is a very costly matter for the boilermaker.

Tube defects as mentioned by the author are difficult to detect, but there is such a thing as damage during transit from the tube works to boiler shop, and this may be serious. This damage can be mechanical or due to damp where plugs have become slack and fallen out. In this district all tubes are sighted again in the boiler shop before going into the boiler and any damaged tube, quickly detected from the internal examination, or badly pitted tube rejected.

Correct alignment is, I agree, a very vital matter and if it is not the practice of the Surveyor to check the "set up" of a new boiler before commencement of tubing, he does, of course, see the entering of the tubes during tubing and can assure himself that the alignment is in order.

The brickwork of most water tube boilers is a matter which we are, I think, apt to neglect and yet from the Owners' point of view can be said to be of the first importance, the upkeep of brickwork in some boilers being a costly affair.

Before finishing my remarks, I cannot resist the temptation of mentioning an incident which occurred some time ago at the final examination of the steam drum of a large new water tube boiler, and brought to my mind by the mention in the paper of "Tubes cut to incorrect length". Two experienced Engineers came out of the drum within an hour of each other, and complained to the head boilermaker that he had two short tubes in the drum. For the benefit of my younger colleagues, who may not have surveyed many water tube boilers, I might perhaps mention that these two tubes were "arbored" or sunk into the tube hole to allow the drum to be properly drained; this is a common practice in some types of water tube boilers.

MR. C. J. SALIARIS.

With reference to tubes, I think the author will agree that in a well designed water tube boiler, it is their condition, more than of all other boiler parts, which determines the installation's ability to continue in useful service, free from failures and the consequent delays and dangers. As far as their external wastage is concerned, this can also be attributed to the abrasive effect of gritty fuel which was often supplied during the war years. Discoloration effects and rust caused by moisture on the fire side can easily be avoided by frequent removals of the deposits and by proper maintenance when laid up.

But it is when we have to form some conception of the internal condition of the tube that the Surveyor's experience and ability to explain (as well as to locate) the various wastages become imperative. The Admiralty have evolved tables from which the expected durability of the boiler tubes can be roughly estimated. This figure obtained has a great influence on the subsequent treatment and strictness of surveys held during the remainder of a naval boiler's life. The following formulæ have been derived as a summary of these tables, and it would be interesting to have the author's views on their applicability in Merchant Service practice in their present or in a modified form.

$$\text{Durability in years} = 10 - \left(\frac{R}{19 - t_o}\right)$$ for generating tubes $\frac{7}{8}$" to $1\frac{3}{4}$" dia.

$$= 12 - \left(\frac{R}{18 - t_o}\right)$$ for generating tubes about 4" dia.

$$= 8 - \left(\frac{R}{21 - t_o}\right)$$ for superheater tubes.

Where R = total reduction in thickness in thousands of 1"
t_o = original thickness in S.W.G.

These expressions do not apply to a general or rapid reduction of the tubes' weight per foot run, but to localised wasting or pitting. Such pitting has often been attributed to defective material and indeed when the scale has been removed a slightly bulged hard oxide crust can be easily mistaken for a lamination. If, however, this crust is broken, a soft active sludge comes to light which seems to eat away the metal in spite of its complete and airtight cover. A theory exists that this action is an electro-chemical one. These "scab" pittings, as they have been termed, have been seen in tubes, and the writer would be obliged if the author gave his experiences in this respect and stated what steps, such as zincing or other methods, he considers best for their prevention or arrest. A few words on the general effectiveness or otherwise of zinc slabs would be also much appreciated.

Reference, it is believed, should have been made to the importance of freedom for expansion, and the securing arrangements. These are particularly important in the case of Yarrow and similar boilers, where the total weight of the steam drum and the weight of most of the water is carried by the tubes themselves. It is imperative, therefore, that the shoes be inspected at every survey and their clearances checked since a restriction in the athwartships direction either under the hydraulic test or operating conditions can cause straining of the tubes, particularly where they enter the water drums.

REPLIES.

To Mr. Gibbeson.

The number of caps removed is a matter for the Surveyor concerned, but I thought that up till quite recently the largest marine unit was in the region of 50,000 lbs. per hour evaporation and I suggested that all caps might be removed, but contended that with larger units my original figure stood, viz., 33 per cent. of those other than the fire rows and circulating tubes.

One of the important things in surveying large units when only a percentage of the caps are removed is to insist that the personnel in charge keep an accurate record of the tubes examined so that every tube may be examined at least once in every three years.

The internal blister is not uncommon in tubes and can be more or less placed in the category of a latent defect, the sectional position deciding whether the blister appears internally or externally.

To Mr. Nicholson.

The erosive effect caused by impingement from soot blowers is an important point and should receive close attention during survey. For the benefit of those who have not come in contact with this defect, I may say that it is usually located in the most awkward places in the tube nests.

The Lamont boiler is a forced circulation unit and can hardly be generalised with the other units employing natural circulation. Provided no defects are noted in the boiler, the request for an hydraulic test appears hardly necessary, but I would suggest that a periodic test, say every three years, would meet the particular case, although in multicap boilers the wisdom of a regular water test after each cleaning has been proved over and over again.

In my opinion the circulating pump should be surveyed annually.

The deep pitting in boiler shells need hardly cause concern so long as it is isolated and inactive, but should any case be considered to require attention I see no reason why welding should not be employed, provided the preparation of the affected plate was such as to afford effective penetration; I would suggest that the welding should be buffed flush with the parent plate.

This is a personal opinion, and it is understood that in cases where such repairs are proposed the matter should be submitted to the Head Office for consideration.

To Mr. Champness.

This contribution is particularly interesting because it deals with points of practical experience. Each case must be dealt with on its merits.

Circulation throughout a water tube boiler is of paramount importance and correct direction of flow in all tubes at all rates of evaporation must be safeguarded as it is often found that local stagnation and even reverse flow occurs at certain evaporations.

I am inclined to adhere to my definitions of blisters and bulges because I cannot agree that a blister is a bulge or vice versa.

At this stage it would be deemed unwise to tackle the question of caustic embrittlement, but experience proves that this defect can lead to

disastrous results if not dealt with in time. The evidence as quoted by Mr. Champness is good guidance. Every rivet head in the boiler should be tested.

The case of B & W boiler tubes having isolated pit marks is not rare and may be assumed to be caused by inferior material or inclusions located at these spots and the impurities contained therein being corrosive agents. Usually it is found that not single tubes are affected but quite a large number of the consignment of tubes used in the boiler.

To Mr. Brown.

It is noted with interest that the Navy realised in the early days that the Scotch boiler was the ideal unit for easy steaming. The testing of the condenser at each survey is certainly a point worth considering, although with better trained personnel we shall cease to worry about this side of the plant.

To Mr. Southwell.

"Tight casings are as important as tight joints." One of the main risks of allowing brickwork and casings to deteriorate is fire and general overheating.

To Mr. Brooke Smith.

My lack of faith in the feed water regulator is surely a misunderstanding. My intention was to emphasise the necessity of overhauling the mounting at frequent regular intervals rather than leaving it until something goes wrong.

Shortage of water can occur with oil fired water tube boilers due to uneven firing, and usually happens when the engines are being manœuvred.

Regarding the excessive hogging and sagging of tubes, I refer Mr. Brooke Smith to Mr. Brown's contribution and to Mr. Champness' remarks regarding bulges and blisters, whilst the testing of boilers has already been dealt with above.

To Mr. Horne.

The setting of the safety valves is one which has been more or less settled in recent times by adjusting the superheater valves at approximately the working pressure and the main valves about 4 per cent. higher.

To Mr. Chambers.

The interpretation of the reason for hogging and sagging of tubes is no doubt correct and should be added to my list.

The fine cracking of tubes generally associated with overheating is only noticeable in cases of slight overheating or burning of tubes usually connected with local deposit on the water side, or impingement.

The majority of engineers agree that banked fires have a depreciating effect on the life of a Scotch boiler, and, in my opinion, this also applies to boilers of the water tube type. Steam can be raised very quickly in these units, and unless it is a case of extreme urgency, why bank the fires?

To Mr. Stuart.

One of the points raised does not appear to be one which would normally come within the province of the Surveyor, but nevertheless it is vitally important that, when overhauling the internal fittings, all loose nuts and bolts, &c., should be kept together in a container and not allowed to foul the tubes.

To Mr. Ewing.

A word of thanks, not only for the present contribution but for his paper written in 1928 to which I made reference in my opening remarks.

The wastage of short connecting nipples between headers and drums in B & W boilers is quite common and should be carefully looked for at surveys.

To Mr. Rennie.

The necessity of maintaining the steady flow of gases through the passes cannot be overstressed. Cases of overheating can be attributed to neglect of this when banks of tubes are allowed to become choked.

The figure of 2 in. deformation over a tube length of 12 ft. seems to have drawn various opinions. If the history of the case is available, then discretion may be used, as there is no empirical formulæ governing the amount of deformation allowed.

To Mr. Thomas.

In both old and new work, when the necessity of removing tubes arises, a considerable amount of care in cutting out the tubes is required to ensure that the landing in the drum or header is not impaired.

One of the outstanding differences between Scotch boilers and those of the water tube type is the fact that in the former the Surveyors have no real concern with the brickwork, whereas in the latter the brickwork is, in my opinion, of paramount importance.

To Mr. Saliaris.

This contribution, like Mr. Brown's, is based on naval practice; there is, in fact, some continuity in the two contributions. To some extent they may be applied to merchant navy practice, but with limitations.

I am afraid the academic formulæ would be too much of a weapon to use against the Surveyor should he condemn tubes before the end of their theoretical life. In my opinion, it is more beneficial to leave the matter to the judgment of the Surveyor, who can then treat each case on its merits.

The use of zinc slabs in water tube boilers is rather limited, due mainly to distilled feed water being used.

In conclusion, I wish to thank my colleagues for the manner in which they have responded with their contributions, which greatly enhance the value of the paper.

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SHIP WELDING AND THE INFLUENCE OF RESIDUAL STRESSES.

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SHIP WELDING AND THE INFLUENCE OF RESIDUAL STRESS.

DURING the war few problems of scientific interest and practical importance attracted so much international attention as the principal failure of some few of the large number of all-welded vessels built in U.S.A. under the emergency shipbuilding programme—the sudden and extensive fracturing of deck and shell plating without apparent cause and leading to total or near-total loss. Initial investigation yielded negative rather than positive results and a more comprehensive series of investigations was then embarked upon by the authorities both at home and abroad, still proceeding but part published and well worthy of careful consideration for due appreciation of all argument.

On the subject of locked-up (or residual) stress, official findings have been briefly summarised as follows* :—

(*a*) Regardless of the procedure, sequence or restraint, every welded structure (unless stress relieved) contains local locked-up stresses up to the yield point of the material.

(*b*) Provided that the material, including the weld, can behave in a normal ductile manner, then locked-up stresses due to welding do not impair the strength of ships' structures.

Investigations carried out for the Admiralty Shipwelding Committee have shown that mild steel from some of the ships which have failed is liable to fracture in a brittle manner, with low energy absorption, if a notch is present, at temperatures well within the service range. While this behaviour has rarely been observed in steel of British manufacture, the factors influencing its occurrence are being thoroughly examined at Cambridge University and with the collaboration of the British Iron and Steel Research Association.

An important conclusion from the Admiralty Shipwelding Committee's deliberations is "that welding as a process for building ships has been entirely vindicated. Given sound design, good workmanship and tough steel, the reliability of welded ships is beyond question."

This survey and investigation was initiated pre-war and therefore to some extent preceded the official inquiry; it had its origin in a study of fracturing observed and dealt with in the course of ordinary survey duties and there remained to complete certain tests planned pre-war, postponed on account of the war and resumed, with Lloyd's Register Committee approval and support, when these spectacular failures occurred.

It has been said that if the spirit of independent inquiry had never been fostered, many a revealing fact and opinion would not have been disclosed. This account of experience and test is offered in that spirit, a contribution to the complicated task of finding a comprehensive explanation.

Results and general conclusions were briefly advised during these war-time tests, each conducted as opportunity offered, but a more complete statement is now possible, duly linking survey experience with test results now more carefully analysed, and confirmed where further test seemed advisable.

* "The work of the Admiralty Shipwelding Committee," by Sir Amos L. Ayre and G. M. Boyd. I.N.A., 1946. See also "Developments in British Shipbuilding," by R. B. Shepheard. BSc. (International Congress on Technical Progress, Brussels, 17th May, 1946.

It is, of course, fundamental to the welding process that certain parts of the weld, as laid, will contain stresses up to the yield point of the weld metal, but all parts of a weld need not contain stresses of that order, nor indeed are they necessarily of the same sign—some may be tensile and others compressive—and so we can distinguish between the locally high value in a top, middle or bottom layer and the average value of stress in the weld section; the complexity of stress within the weld is the particular concern of the weld metal, and high ductility is an essential requirement for weld metal, but high average value of residual stress may well be the despair of, and cause distress in, the neighbouring structure.

Most failures occur clear of butts and they have occasioned concern for the suitability of the material of which the structure is made, but the suitability of any material is conditioned by constructional and operational requirements, and we can ill blame the material if it fails to respond to exceptional treatment. Careful consideration of the constructional methods adopted in the particular cases under review rather suggests that the structures as built contained stresses of much higher order than those that had hitherto been imposed, and indeed the risk remains since no instructions yet operate to impose a limit on high average value of residual stress—the general injunctions to avoid restraint and to deposit no more weld metal than is necessary have that influence but apparently do not afford sufficient guidance.

In current practice and of all means available to reduce welding costs, too much advantage is being taken of two, each resulting in higher average value of residual stress:—

(1) High restraint for all *in situ* welding due to proceeding from piece-small assembly to prefabricated assemblies of exceptional weight and rigidity.

(2) High heat input due to an ever present tendency to widen the gap (possibly for dual connections) to accommodate large electrodes which permit heavy welding currents.

It is doubtful whether a rule could be formulated to regulate weight, rigidity, width of gap, size of electrode and value of current without encroaching in some way upon legitimate procedure, but the absence of rule should not be regarded as opportunity to proceed to unlimited size of prefabricated parts or failure to recognise that there is a particular rather than a general use for large electrodes and very heavy welding currents.

Due acknowledgement is made of the valuable co-operation of Management and Staff of the following firms in course of these tests:—

The Bute and Channel Dry Dock Co., Cardiff, who voluntarily contributed by making all the apparatus required.

The British Arc Welding Co., Cardiff, who granted all welding and most other facilities.

Acknowledgement of valuable assistance in contributing component parts, loan of instruments and advice on matters within their special knowledge is also due to:—

Messrs. Walter Somers, Ltd., Birmingham.

Messrs. Horsley Bridge & Thomas Piggott Co., Birmingham.

The City Electrical Engineer's Department, Cardiff.

Messrs. John Williams & Sons, Ltd., Cardiff.

Messrs. Guest, Keen & Nettlefolds, Ltd., Cardiff.

Messrs. Skefco Ball Bearing Co., Cardiff.

All tests were carried out at Lloyd's Proving House, Cardiff.

It has, of course, long been recognised that the welded ship presents a problem differing greatly from that of its riveted counterpart. There was need for the initial special notation "Experimental"; differences immediately apparent are that riveting spreads a joint whereas welding contracts it, rivets slip under relatively low load

so that stress is fairly uniformly distributed, riveting is simple to test and the connection is not so rigid, welding has many advantages but not these particular attributes. It creates a more homogeneous structure and introduces many strange internal stresses.

These stresses are variously described as cooling, contraction, locked-up or residual stresses, the latter being the term generally adopted but with modern tendency to differentiate between action and re-action, contraction induces re-action, and residual stress begets re-action stress at all points of restraint; but in a complex structure, re-action stresses in number, position and magnitude are even more elusive than residual stresses, indeed the challenge of re-action stress is but an invitation to reduce residual stress, and so, in order to simplify the isssue, all stresses arising from welding are referred to as residual stresses.

In the search for the likely cause or combination of causes in design, material, procedure and workmanship, due note must be taken of the considerable structural success attending weld construction for shipbuilding purposes throughout the thirty years of its development without near approach to these spectacular failures. Considerable latitude has ever been permitted in design, but little change has taken place in the material generally employed—ship quality mild steel, simply specified and tested, good quality easily attained, ductile and capable of a large amount of plastic deformation, easily worked, cheaply produced and generally available; workmanship might be described as good, the best obtainable under shipyard conditions, no comparison is possible with the standard of workmanship attainable under the ideal conditions of a workshop.

The special notation "Experimental" attaching to vessels in which the principal members are welded was removed in 1932, after due period of exacting test under both normal and abnormal service conditions, and we could then say that whilst design, material, procedure and workmanship were each capable of improvement, they were, at that time, of sufficiently high standard as to ensure, for welded and riveted vessels alike, a safe, sound and serviceable structure, and it is against this substantial background of experience that we now view these disquieting failures—timely warning that in the development of welding we were not sufficiently aware of the importance of some one or two factors.

The search necessarily extends over a wide field, for in these failures no cause was readily apparent, but by this it could be inferred that the error was one of margins rather than by way of wholly wrong procedure. Naturally there will be a period of hesitancy on the part of some Owners to specify wholly welded construction pending an assurance, perhaps a rather unqualified assurance, that all difficulties have been overcome. Shipowners and, no less, Shipbuilders and Underwriters are each apprehensive of the experimental, and with good cause, for ships are costly structures both initially and in lay-up for repair, their voyaging permits of few restrictions other than draft, they have to contend with numerous conditions ill defined in nature and extent, and frequently they are remote from immediate assistance; the policy necessarily applying is one of due margins and not safe risks.

Residual stress is but one of the many stresses experienced by the ship structure, each difficult to evaluate, for we can scarcely say which of the many conditions generally applying, singly or in possible combination, presents the surmounting condition for stress; there is little that is absolute in the calculated stress and no more in its value as a basis for scantlings, but the method is in frequent use and usefully serves its allotted purpose to compare similar structures and to interpret both experience and experiment.

Similarly we may not be able to define sufficiently all the conditions associated with a stress determined by measurement of strain, and many of the most interesting stresses are those which are most awkward to measure as strain. This difficulty is in part overcome by making certain assumptions, but the assumptions more often permit the solution than convincingly reflect actual operating conditions, and so all investigations are but broadly enlightening, each contributing its quota, a series of progressively closer and closer approximations, a hardening

and narrowing process ever converging to the minimum in scantlings that will satisfy normal service conditions. Thus we are largely limited to saying that out of our experience of things as they are, is born our conception of things as they ought to be.

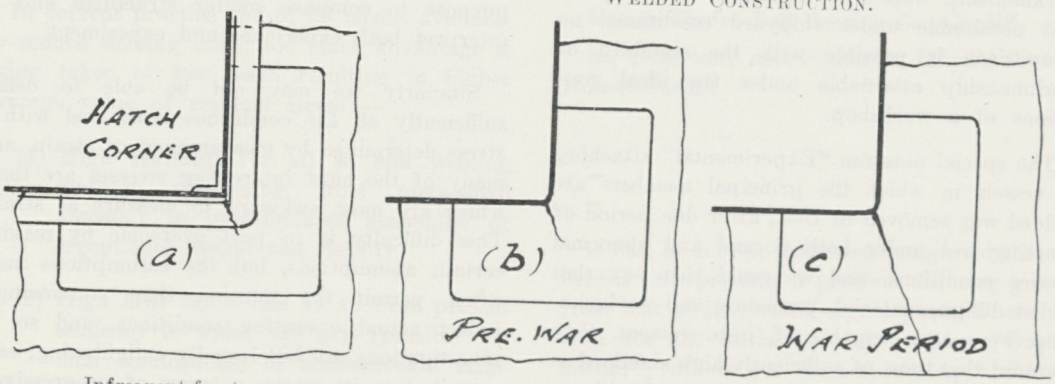
Most naval architects engage in a humble way in scientific work, they understand the scientific way of looking at things and they appreciate no less its limitations in relation to their particular problem. Were it otherwise there would be no need for that institution peculiar to ships: the classification society, duly appreciative of all theory, but dispensing, chiefly, the knowledge derived from a wide and varied experience.

Residual stress, a complex and relatively unexplored subject, especially in the field of quantitative data, has been cited as a possible cause for serious failure. We heard much about residual stress in the early days of welding; it was then, and to a considerable extent still is, a subject for discussion as matter of opinion, for, whilst we can readily see why it develops, we can less readily evaluate the quantity.

All welding gives rise to residual stress because no two parts to be welded can be so "free" as not to resist contraction during cooling; it is a wholly adverse effect and its magnitude is greatly influenced by the quantity of metal deposited, also by the sequence of welding both the individual part and the structure as a whole; indeed, so numerous are the variables that it is impracticable to determine what value of residual stress is initially, and may ultimately be, present in any one part of a complete structure. But since residual stress was so patently inoffensive a factor in the early days of welding, so we found it convenient simply to relegate it as one more unknown added to the many already existing in the ship structure, all comprehensively covered by that margin figuring in design as the factor of safety, hopefully but not assuredly present, the sole criterion of the sufficiency of the structure being the presence or absence of stress effects after the vessel has been subjected to the full range of service conditions.

So we may accept that the structurally satisfactory position pre-war in respect of welding was conditioned by an achieved low average value of residual stress, and we could appreciate no less that any increase in the average value would be tantamount to reducing the overall margin and thereby bringing into sharper relief all those small discontinuities arising from simplified construction—more permissible in the riveted than in the welded structure, as was evident from the odd small fracture occurring more frequently in the latter, but still not extending abruptly, and therefore indicating a purely local concentration of stress self-relieved by limited fracture and easily repaired.

The picture thus presented for general appreciation of maturing defects is as follows:—



Infrequent fracture of limited extent.

Occasional fracture of limited extent.

Tendency towards abrupt failure

It might be thought that once a crack has formed as in (*a*) or (*b*), rupture would result almost immediately owing to stress concentration at the end of the fissure—an "ideal" notch effect. Mathematical considerations would certainly lead to that conclusion, but experience pre-war repeatedly showed that this was not the case; the cracks did not extend appreciably after first becoming noticeable, despite the many reversals of stress subsequently experienced before the vessel reached port. Indeed many of these local fractures were found in rusted condition only at periodic overhaul, and therefore carried for some considerable time without disastrous effect.

That similar fractures (*c*) in greater frequency and magnitude, with little external cause contributing and with definite inclination to extend, should be present in welded ships of later period, rather pointed to the same cause in greater degree, higher residual stress, for the design was the same or better, the material had passed the same acceptance tests, and workmanship was ever improving under a more intensive and enlightened supervision.

As indicated, this survey and investigation was initiated pre-war when welding was first seen as a not very economical rival to riveting if it was not associated with :—

(*a*) a large amount of prefabricated work done on the ground;

(*b*) the use of large diameter electrodes with heavy currents so as to reduce the number of passes required.

Brief consideration rather suggested that these production economies might lead to higher average values of residual stress due to higher restraint and greater heat input. Some probing analytical survey was then due, and the special apparatus in use in these tests was then in the initial stage of development.

These production economies had not then come into operation on any large scale, few shipyards had available the extra space required, the heavy duty welding plant and the necessary lay-out of high-powered transporting cranes; the full conversion entailed considerable capital outlay and no small regard for the Shipowners' preference, for not all were attracted to welding, but it could be said that their limited adoption yielded quite satisfactory results structurally and no small advantage economically. Had the war not intervened, progress would no doubt have followed on conventional lines, easy stages each successively proved and the economic/structural high level thus determined.

Military need intruded to dictate no further slow process of enlightenment. New shipyards were laid down replete with all the space, cranage and welding equipment necessary for mass production on a high power basis, but no tool in use, not even an automatic tool, supplants wisdom. The power handed out to the operators outstripped all knowledge of what would ensue; the "Ocean" class was not free from initial fracture in building and some rather unsightly buckling—a form of stress relief—but subsequently proved very successful in service. The more advanced methods of construction adopted for their immediate successors included these spectacular failures.

These failures then, were not inconsistent with the tendency previously observed—ever higher demand on the material employed due to higher average value of residual stress. So-called self-fracturing is no new experience, and, of all possible factors contributing, one especially must be present—high stress.

The principal factors for high residual stress are :—

(*a*) High restraint;

(*b*) Short distance between points of restraint;

(*c*) More than the necessary heat input for a satisfactory weld.

It will be readily conceded that the addition of weight and stiffness to parts which are then to be welded together is synonymous with the more conventional methods of fixing them, in terms of restraint it matters little whether we securely dog down two parts to be welded or so add to their weight and stiffness as to render them practically immovable, and so, in proceeding from piece-small assembly to large prefabricated assembly, we proceed from low restraint to high

restraint, a procedure which, in the extreme, is quite at variance with the general injunction to avoid restraint.

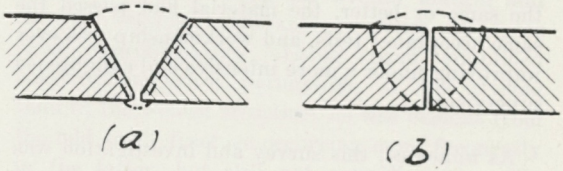
It is difficult to particularise on values of restraint; all we can say is that the extent to which they have increased in new construction can, on occasion, fall little short of what frequently applies in Repair work. In these tests the primary aim was simple: only to determine the stress-producing effect of, and then to compare, various forms of butt weld under the condition of simple restraint (ends only). Fair comparison demanded a uniform degree of restraint throughout the series and that the degree of restraint should be representative of the less simple form of restraint present in actual practice; the values chosen—87 per cent.—is that which has been deduced by simple calculation for typical repair to a principal strength member.

The distance between points of restraint has important bearing since, for a given stretch, the stress decreases as the distance between points of restraint increases.

All will agree that welding, properly carried out, is a highly efficient method of joining two parts, but it usually costs more to prepare a gap and fill it with weld metal than to make holes and fill them with rivets, and it was an endeavour to diminish the difference in cost that chiefly led to the adoption of large-gauge heavy-current welding. Now the merit of saving in cost is not in question so long as the finished product is equally good in service. Putting first things first, we can say that the factors which should determine the gap, size of electrode and current value are the efficiency requirements of the principal connection, and secondly, the question of cost. For no work of primary importance should the opportunity for dual connection or the question of cost take precedence. Small to medium gauge electrodes carrying no more than the necessary currents are not out-moded; in conjunction with suitable gap they still provide adequate penetration and all the physical properties necessary for a good weld, and, moreover, they are easier to handle. What emerges from these tests is that the use of wider gaps and larger electrodes to permit heavier currents than are necessary to provide a good weld introduces greater heat input, and therefore higher average values of residual stress for a given degree of restraint, and, if restraint is raised, then still higher average values ensue.

In practice there can be no condition of restraint-free. It may be small for the first run but each succeeding run will be constrained by the preceding run. Nor can there be a condition of 100 per cent. restraint since the attachment, no matter how strong, will yield elastically. Residual stress in the direction of length of weld being inevitably high, it is advantageous to position the length of weld transversely, that being the direction in which subsequent superimposed stress is likely to be least.

In general, all butt welds fall into one of two categories, or a combination of both:—



The dotted lines indicate the area of fusion, as can readily be seen on an etched specimen.

(*a*) Veed butt welds: in which the large proportion of the metal fused is "deposited" and only a low rate of heat input is required to accomplish that purpose satisfactorily.

(*b*) Square butt welds: in which the large proportion of metal fused is parent metal and a high rate of heat input is required to ensure depth penetration.

The gradient, or the rate at which temperature varies at different points away from the weld, depends chiefly upon two factors:—

(1) Rate of heat input;

(2) Capacity of the parent metal to absorb heat, and this will depend on the temperature, heat conductivity, mass and specific heat, and the greater the rate of heat input the deeper and wider is the resulting weld.

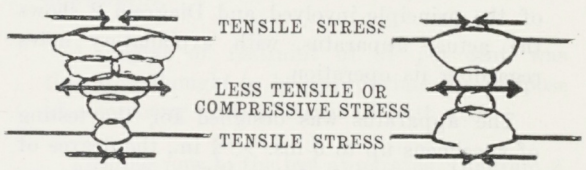
Butts of the square butt type were introduced mainly to cheapen the cost of production, by dispensing with or lessening machine preparation, but both experience and test point to this form of butt being that which weld construction should concentrate upon.

As width of gap increases and root face decreases so there is need to reduce the rate of heat input to no higher value than is necessary for adequate penetration, and since we can say with considerable assurance—by virtue of pre-war experience—that the standard vee and double-vee preparation with weld made by small to medium gauge electrodes carrying no more than the necessary current was satisfactory, so, in order to provide the same margin as pre-war, all variations of gap, gauge electrode and current should combine not to exceed that standard for heat input. Just what that means in practice is exemplified in the Diagram 4 and the associated summary of test results.

Generally we must view the welded ship structure as one carrying a complexity of residual stress, with local values subject to many influences, and so the search for any representative value by calculation or measurement of strain presents many difficulties; at best we can but plan to ensure low values. Subsequent redistribution of stress only takes place while the material remains plastic, for, when in ductile material at a stress concentration, the proportional limit and yield point are passed, plastic flow begins and redistribution of stress takes place, accompanied by a certain amount of strain hardening. In brittle material the effect of plastic flow is small, and the consequences of stress concentration are serious—hence the importance of ductility in shipbuilding material; but the ductility in shipbuilding quality mild steel may not suffice if average value of residual stress, as distinct from local value, is to be unduly high.

Before proceeding to a description of the apparatus used and the results achieved, it may be of interest to state what advantage this method of test possessed over the usual method of determining stress by linear measurement of strain.

In order to ensure reasonably accurate and comparable results in tests it is, of course, desirable that the loading should be applied axially, that the degree of restraint remains constant and that the measurements taken for strain will have due regard for any angular distortion arising. Simple linear measurement as by strain gauge presupposes no change in the horizontal and vertical planes, yet welding can seldom be carried out without some deformation of the parts. These considerations suggest the use of short base strain gauges of very high degree of accuracy, yet not so delicate as to be negatived by heat effects and the shock of deslagging the various runs, or, if removed during the protracted period of test after taking zero readings, ensuring on replacement the exact contacts previously obtaining. The risks of included error are therefore very real whatever length of base is adopted. It is also appropriate to mention that, except when the weld is annealed, there can be no uniform distribution of stress in the vicinity of the weld; the outer layers of weld metal may be stressed up to the yield point in tension whilst some part of the interior of the weld is in a state of compression. The mean of the strain readings taken on the upper and lower surfaces in the vicinity of the weld is therefore no measure of the average value of residual stress in way:—



So long as external restraint applies, the benefit of annealing—other than improving the grain structure—is to level up all differences in stress in way of the weld to the average value of residual stress obtaining clear of the weld. Local annealing does not reduce the average value of residual stress except by causing buckling and, if no buckling occurs, higher residual stress may ensue.

Due consideration of all the complexities associated with the measurement of strain by strain gauges led to the adoption of this other

method—applicable only for test specimens and with purpose chiefly to compare the various forms of butt weld advocated—the measurement of strain energy rather than strain, entailing not the accurate measurement of numerous small linear changes, but only the measurement of their nett effect.

From a general analysis of readings taken during these tests it was thought that volume of electrode used could be directly related to arc energy and total current consumed, but some verification seemed desirable. Separate tests were therefore made in a simple form of calorimeter with arrangements as shown in the photographs.

Welding time for each run, total welding time, amps., volts, volume of electrode deposited (and wasted, with equivalent heat loss), total current consumed (watt secs.) and arc energy $\frac{\text{(watt secs.)}}{4{\cdot}18}$ were each accurately measured and the heat remaining in the specimen on completion of welding was determined by the rise in temperature of the known weight of water in the calorimeter, the specimen being suspended with its lower surface in contact with the water which by special means was kept circulating during the progress of welding. As soon as welding was complete the specimen was submerged and agitated until the maximum temperature of the water was noted.

In this series of twelve Heat Input Tests, the amount of heat (calories) remaining in the specimen on completion of welding, and expressed as a percentage of the arc energy $\left(\frac{\text{watt secs.}}{4{\cdot}18} = \right.$ calories) was found to range from 49 per cent. to 75 per cent. and appeared to be unrelated to any of the factors—form of joint, gauge of electrode, rate of heat input, number of runs and duration of welding—but the volume of electrode deposited was roughly proportional to total current consumed. The conditions of test do not, of course, simulate practical conditions, and so we must expect, as indeed we find in the stress tests, even less harmony under practical conditions.

TEST APPARATUS AND RESULTS.

Diagram 1 is included for ready appreciation of the principle involved and Diagram 2 shows the actual apparatus, with explanatory notes regarding its operation.

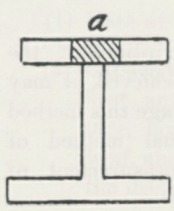
The apparatus was designed for the testing of specimens up to 6 ins. $\times$ $\frac{3}{4}$ in., the degree of restraint provided being 87 per cent.—*see* Diagram 3. There is provision for testing specimens up to 8 feet between points of restraint, but it was found necessary to adopt the 8 feet length for the 6 ins. $\times$ $\frac{3}{4}$ in. specimens in order to ensure that average residual stresses for that series would not exceed the yield point, and this in itself is of special interest—average residual stresses of the order of twice those indicated would have resulted if the length between points of restraint had been reduced to 4 feet.

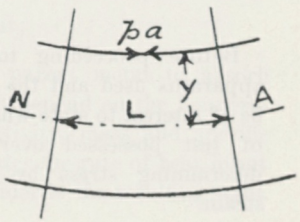
Considerations leading to the adoption of 87 per cent. degree of restraint were as follows :—

If, when ends x y are free, the reduction in length L due to welding is denoted by d, then, when ends are restrained, a residual stress p is induced and the reduction in length L is :—

$$d - \frac{p\,L}{E} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

But the structure, of which the above section forms a part, must contract locally by equal amount :—





Let a be the sectional area in way of the butt weld and A the sectional area and I the moment of Inertia of the remaining structure, then the compressive stress in the top flange will be $\frac{p\,a}{A}$ due to the direct load on the structure plus $\frac{p\,a\,y^2}{I}$ due to bending, and this for length L corresponds to a reduction in length of $\frac{L}{E}\left(\frac{p\,a}{A} + \frac{p\,a\,y^2}{I}\right)$ or

$$\frac{p\,L}{E}\left(\frac{a}{A} + \frac{a\,y^2}{I}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Equating (1) and (2) we have

$$d - \frac{p\,L}{E} = \frac{p\,L}{E}\left(\frac{a}{A} + \frac{a\,y^2}{I}\right)$$

$$\therefore \quad p = \frac{d\,E}{L}\left(\frac{1}{1 + \frac{a}{A} + \frac{a\,y^2}{I}}\right)$$

If restraint were absolute then L would suffer no reduction of length and $\frac{p\,L}{E}$ would equal d and $\frac{1}{1 + \frac{a}{A} + \frac{a\,y^2}{I}}$ would be equal to unity, so that, for this form of elastic restraining structure, we can say that $\frac{1}{1 + \frac{a}{A} + \frac{a\,y^2}{I}}$ is representative of the degree of restraint present.

Taking now a particular example, typical of many dealt with in repair and of interest in prefabricated construction, namely all welding completed except for the necessary welding of a butt port and starboard in the upper deck stringer plate, the seam attachment being left free for a length $\frac{L}{2}$ each side of the butt pending completion of the butt weld.

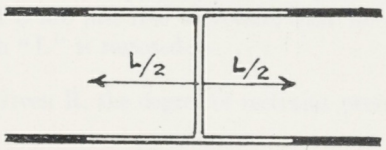


FIG 1.

For Fig. 1 taking typical values :—

a = 80 sq. ins.
A = 2100 sq. ins.
I = 400,000 ft.^{2} ins.^{2}
Y = 23 ft.

then $\frac{1}{1 + \frac{a}{A} + \frac{a\,y^2}{I}} = \frac{1}{1 + \frac{80}{2100} + \frac{80 \times 23^2}{400{,}000}}$

= ·87 or 87 per cent. degree of restraint.

From this it will be apparent that the degree of restraint increases as the sectional area for completion of welding decreases, and increases as distance away from the neutral axis decreases;

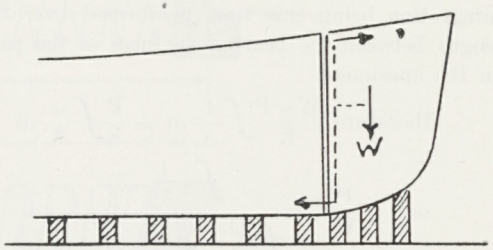


FIG 2

also it will be apparent as in Fig. 2 that for the *in situ* weld joining large prefabricated parts, both weight and moment of weight contribute an appreciable initial restraint even when welding is commenced at the level of the neutral axis and proceeds simultaneously upwards and downwards.

A degree of restraint of 87 per cent. was therefore thought to be appropriate for purpose of comparing various forms of butt weld.

Turning now to the test apparatus, Diagram 2, it will be seen that the restraining box when re-acting to a tensile load P tons in the specimen, contracts an amount equal to $\frac{P}{E}\int \frac{1}{A_r}\,dl$ where A is the sectional area of the restrainer varying throughout its length due to access holes, etc. (the integration being performed over the length between the bearing surfaces of the pins on the restrainer, Diagram 3) so that when the load is transferred from the pins to the Tensile Testing Machine, the restrainer, being free of load, returns to its original length, i.e.,

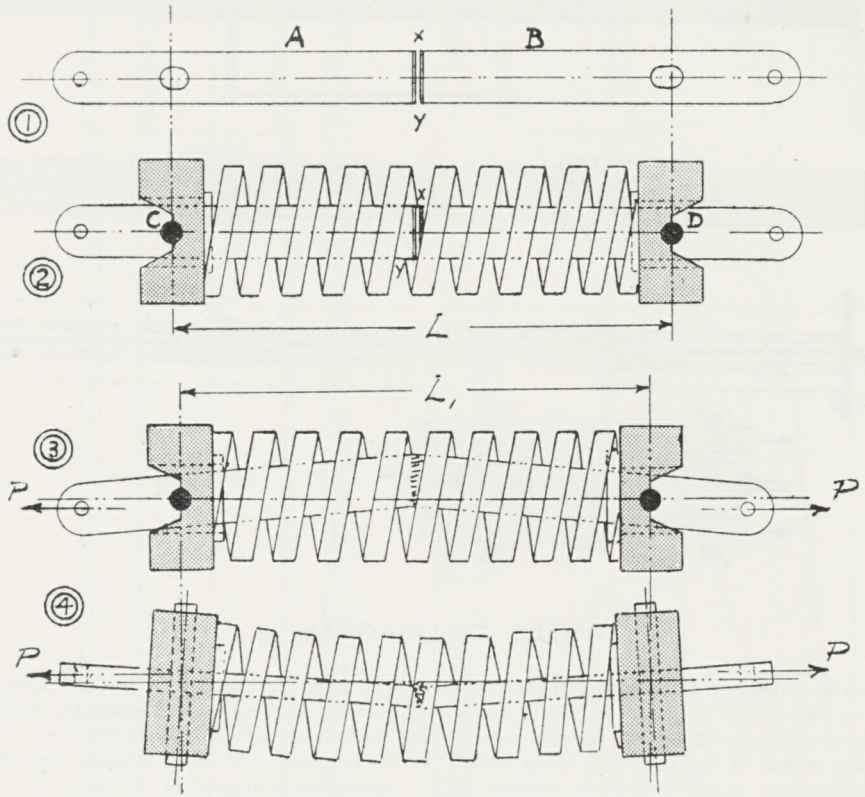
from its loaded length it extends by an amount $\frac{P}{E}\int \frac{1}{A_r}\,dl$. For the pins to be just free to rotate as they were before welding commenced, the specimen must also extend an equal amount and return to the length it had before welding. Now if W is the pull applied by the Tensile Testing Machine the load on the specimen becomes W tons instead of P tons, an increase of (W — P) tons, and the extension of the specimen is $\frac{W-P}{E}\int \frac{1}{A_s}\,dl$, where A_s is the sectional area of the specimen varying throughout its length due to holes, doublers, etc. (the integration being this time performed over the length between the bearing surfaces of the pins on the specimen).

$$\text{therefore } \frac{W-P}{E}\int \frac{1}{A_s}\,dl = \frac{P}{E}\int \frac{1}{A_r}\,dl$$

$$\text{or } \frac{P}{W} = \frac{\int \frac{1}{A_s}\,dl}{\int \frac{1}{A_r}\,dl + \int \frac{1}{A_s}\,dl}$$

Since the specimen has, under the action of load W, then returned to the length it had before welding the butt, W is the re-action that would be set up under a condition of absolute restraint and $\frac{\int \frac{1}{A_s}\,dl}{\int \frac{1}{A_r}\,dl + \int \frac{1}{A_s}\,dl}$ is the fraction denoting the degree of restraint provided. The restraining box is therefore so designed that with $6 \times \frac{3}{4}$ ins. specimens, which were mainly used, the degree of restraint is approximately 87 per cent. For $\frac{5}{8}$ in. specimens, the degree of restraint would be slightly higher, 89 per cent. Actual conditions having been simulated, the results, for comparative purposes have all been presented on a basis of 100 per cent. restraint, i.e., the tabulated stress is $\frac{W}{A}$ where A is the sectional area of the specimen in way of the weld and W is the load applied by the Testing Machine for release of the pins.

DIAGRAM 1.



NOTES ON DIAGRAM 1.

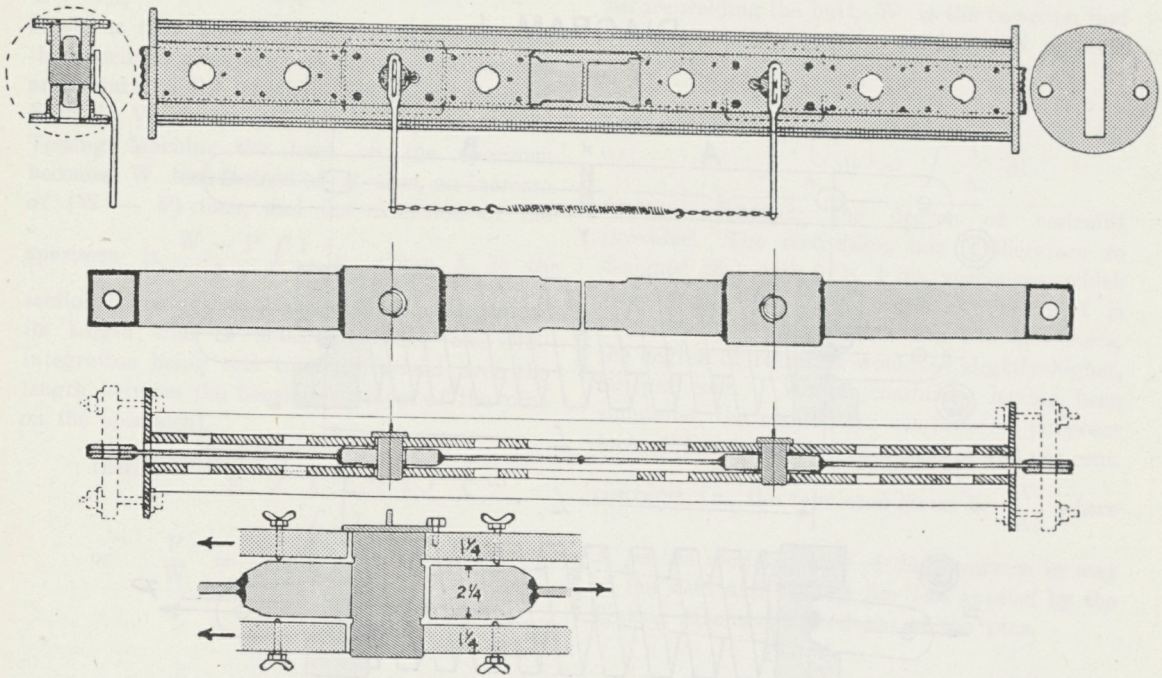
FIGS. 1 and 2 represent the set-up of the apparatus; the strong helical spring represents the outer casing, with the two parts A and B of specimen inserted so that pins C and D are just held in place by bearing on the end attachments of the spring. Thus arranged there should be the requisite gap at X Y for welding, and the axial length is "L".

FIGS. 3 and 4 indicate the resultant compression of the spring due to contraction in the weld.

If now we apply an outward pull P, thereby stretching the specimen to an extent that the pins C and D are just free to rotate, then we will have released all compression in the spring, i.e., the axial length "L" is restored:—

Given R, the degree of restraint present then $\frac{\text{P R}}{\text{sect. area of specimen}} = \text{Average Residual Stress in specimen due to welding.}$

DIAGRAM 2.



NOTES ON DIAGRAM 2.

The apparatus is designed for specimens up to 6″ × ¾″ in section in way of the test weld and up to 8 feet distance between centres of restraint; the disc ends on the restrainer permit of the apparatus being rolled over for convenience of all down-hand, vertical or overhead welding; the restraining pins are 3″ in diameter, nickel steel with polished and slightly lubricated surface for minimum friction when rotated, and deep bearing surfaces are provided specially ground-in so as to afford full bearing contact on the half circumference of the restraining pins.

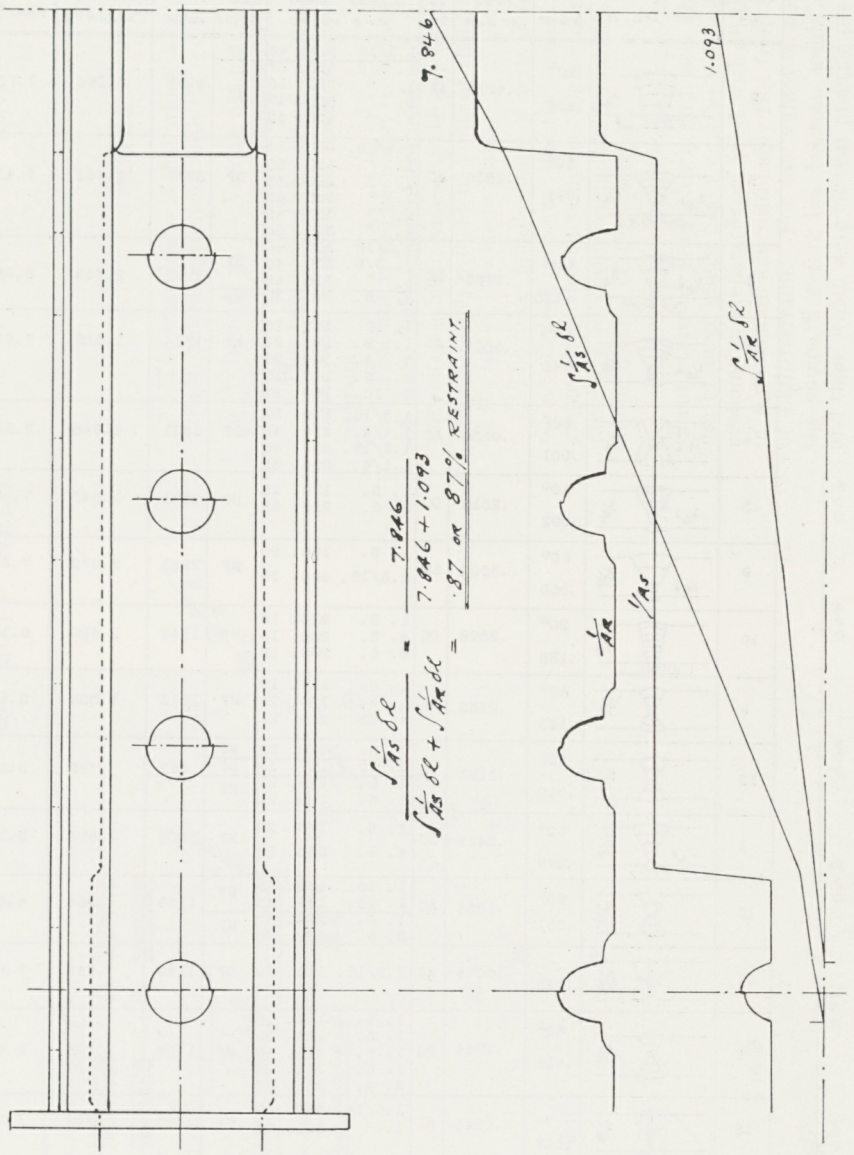
In operation, the two parts of the specimen, with butt prepared in advance — as shown in the middle sketch — are inserted into the restrainer and the restraining pins fitted; the specimen is then centralised in the cavity of the restrainer by means of the round nosed set screws indicated in the lower sketch, and pressed hard home for contact on the bearing surfaces of the restraining pins by means of end straps (shown dotted); the levers which rotate the restraining pins and the stretched spring which operates the levers, are then fitted, and the end straps carefully eased off until the stretched spring just overcomes friction at the pins to allow them to rotate. The weld is then effected and the resulting contraction in the specimen, locks the restraining pins; the end straps are then removed and the centralising set screws withdrawn. When cooling is complete — at least 6 hours were allowed — the apparatus is aligned in the test bed of a horizontal tensile testing machine and a pull applied to the ends of the specimen and gradually increased until restoration of the original length is automatically indicated by the stretched spring and levers again overcoming friction for the restraining pins to rotate. The pull required for this to happen is noted and three such readings were taken for each test.

Throughout the series of tests, the load required to rotate the pins is the mean of 3 readings, no two of which differed from the mean by more than ·6 ton corresponding to a maximum error of one-eighth ton per square inch in average residual stress.

In some tests the restraining pins were removed after the test for residual stress, and the pull increased up to the value required to fracture the specimen.

In other tests all welding was carried out with the apparatus initially positioned in the test bed and readings for residual stress were taken at intervals throughout the welding operation.

DIAGRAM 3.


7.846
1.093
$\frac{\sqrt{I_{AS}}\,dz}{\sqrt{I_{AS}}\,dz + \sqrt{I_{AE}}\,dz} = \frac{7.846}{7.846 + 1.093} = .87$ or 87% RESTRAINT

SUMMARY OF TEST RESULTS IN ORDER OF STRESS VALUES.

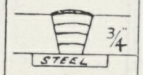
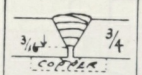
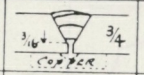
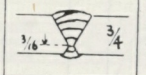
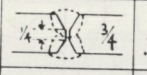
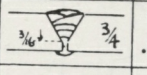
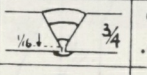
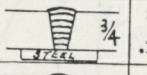
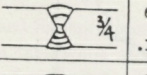
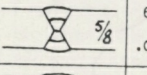
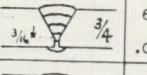
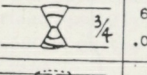
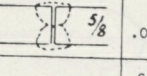
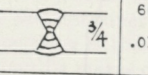
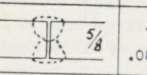
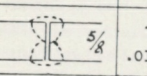
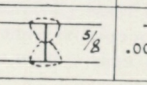
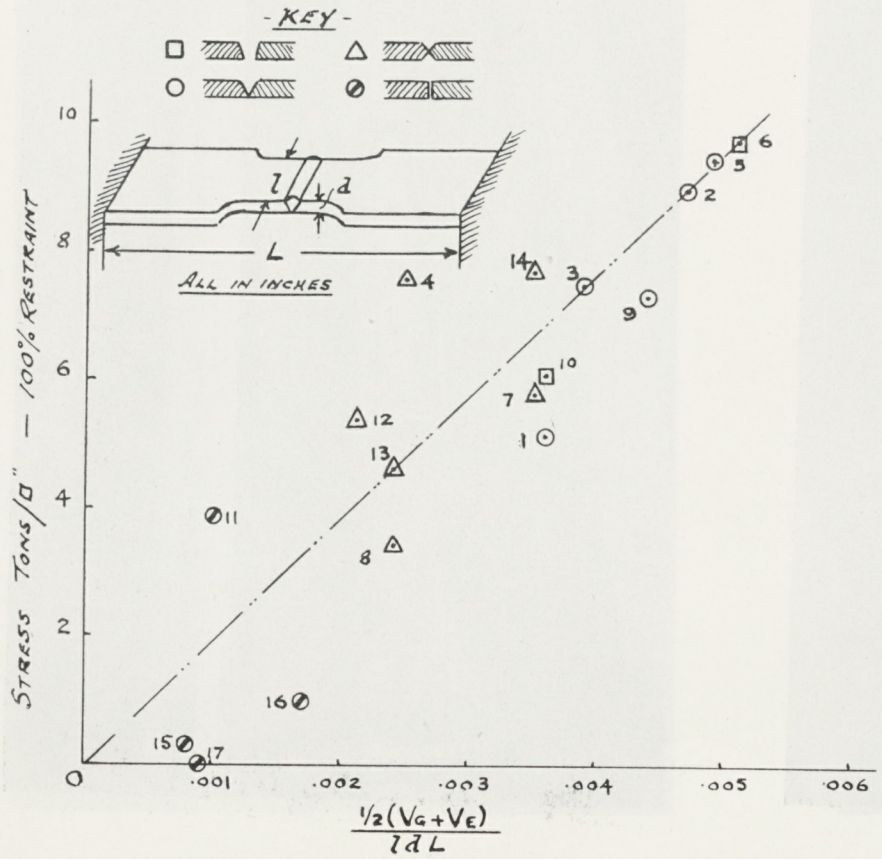
Test No	Section of Weld	Angle & Gap	Sect° Area of Gap	A.C. or D.C.	No. of Runs Gauge, Amps and Volts	Type Elec-trode	Kilo Watt Secs	Volume Electrode Consumed	Stress Tons°
6		20° .438	.4273	AC	1.5/16. 505. 48 1. 3/8. 550. 37 1. " 580. 30 1. " 500. 47 1. " 400. 32	DP MP	4237	3.265	9.78
5		60° .095	.2536	AC	1.5/16. 450. 53 1. " 480. 50 1. " 325. 35 1. " 525. 45 1. " 325. 40 1. " 310. 35	DP	3737	2.761	9.45
2		60° .125	.2766	DC	1.5/16. 300. 40 1. 3/8. 330. 40 1. " 315. 40 1. 8. 180. 30	DP MP	2747	2.455	8.98
14		60° .045	.2511	AC	1. 10. 155. 25 1. 8. 188. 21 3. 4. 300. 23 1. 8. 160. 19 1. 10. 160. 22	MP	1764	1.529	7.67
4		60° .001	.0730	AC	1.5/16. 570. 57 1.1/4. 350. 40 1.5/16. 600. 60 1.1/4. 260. 35	DP	3581	1.648	7.58
3		60° .092	.2516	DC	1. 8. 170. 25 6. 6. 210. 28	MP	2671	1.843	7.49
9		60° .060	.3002	AC	1. 8. 130. 20 2.5/16. 400. 30	MP	2243	2.072	7.33
10		20° .188	.2398	DC	1. 8. 210. 15 4. 8. 200. 15 2. 6. 230. 12	MP	1148	1.680	6.12
7		60° .125	.2562	DC	1. 8. 110. 18 1. 8. 150. 20 4. 6. 210. 23	MP	1813	1.500	5.8
12		60° .010	.1191	AC	1. 8. 128. 22 1. 10. 127. 33 1. 6. 228. 21 1. 6. 225. 21	MP DP MP	973	.789	5.38
1		60° .079	.2416	DC	1. 8. 170. 28 4. 4. 230. 32	MP	2506	1.670	5.16
13		60° .031	.1854	AC	1. 10. 132. 35 1. 10. 135. 35 1. 6. 228. 22 2. 6. 232. 22	DP MP	1156	.964	4.6
11		- .012	.0075	AC	2.5/16. 510. 50	DP	1122	.642	3.89
8		60° .016	.1744	DC	1. 8. 150. 18 1. 8. 175. 19 1. 6. 215. 26 1. 6. 220. 25 2. 6. 235. 22	MP	1154	1.105	3.42
16		- .087	.0544	AC	1.5/16. 570. 38 1. " 500. 30	MP	1206	.944	1.02
15		- .012	.0075	AC	2.5/16. 560. 48	DP	995	.575	.27
17		- .001	.0006	AC	1.5/16. 470. 50 1.5/16. 480. 48	DP	1093	.651	-

DIAGRAM 4.

COMPARATIVE VALUES OF RESIDUAL STRESS FOR VARIOUS FORMS OF BUTT WELD.



NOTES.

The base chosen is that which was found to be in closest general agreement with the Test results :—

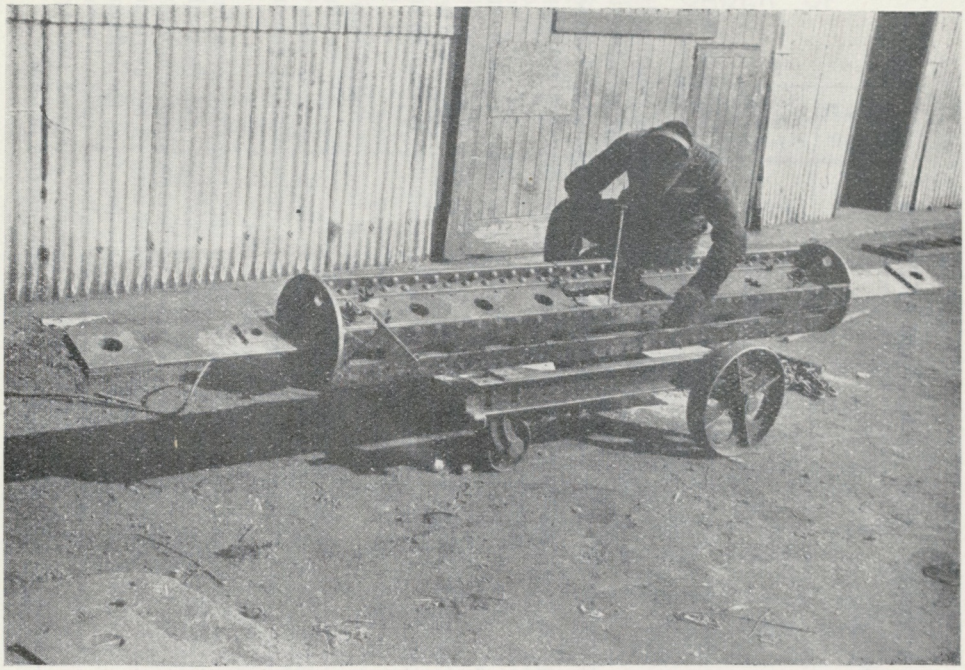
$$\frac{\frac{1}{2}\,(\text{Volume of gap} + \text{Volume of electrode consumed})}{\text{Length} \times \text{Depth (of weld)} \times \text{Distance between restraints.}}$$

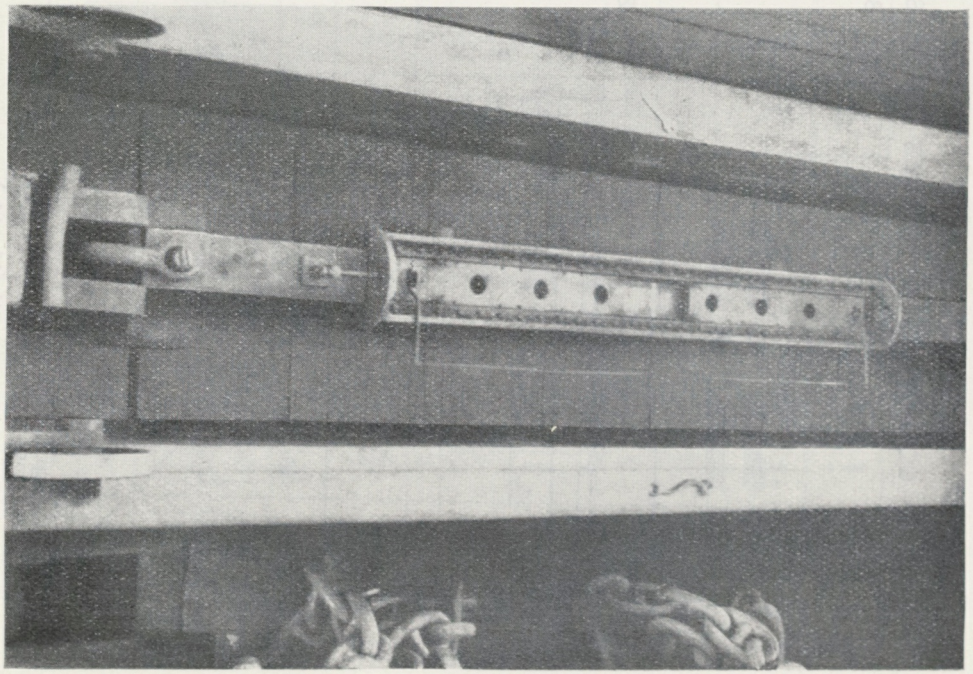
This base reflects the broad relationship between mean width of weld and distance between points of restraint.

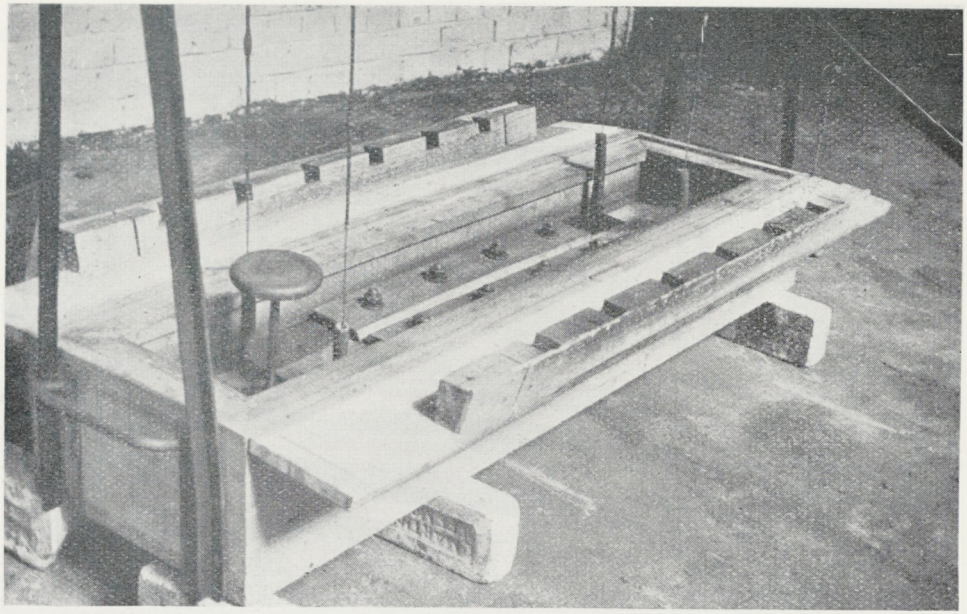
That undue emphasis can be laid on the economy of using large gauge electrodes and heavy welding currents—even to widening the gap to permit of their use—is clearly evident in joints of that type appearing at the top of the stress scale.

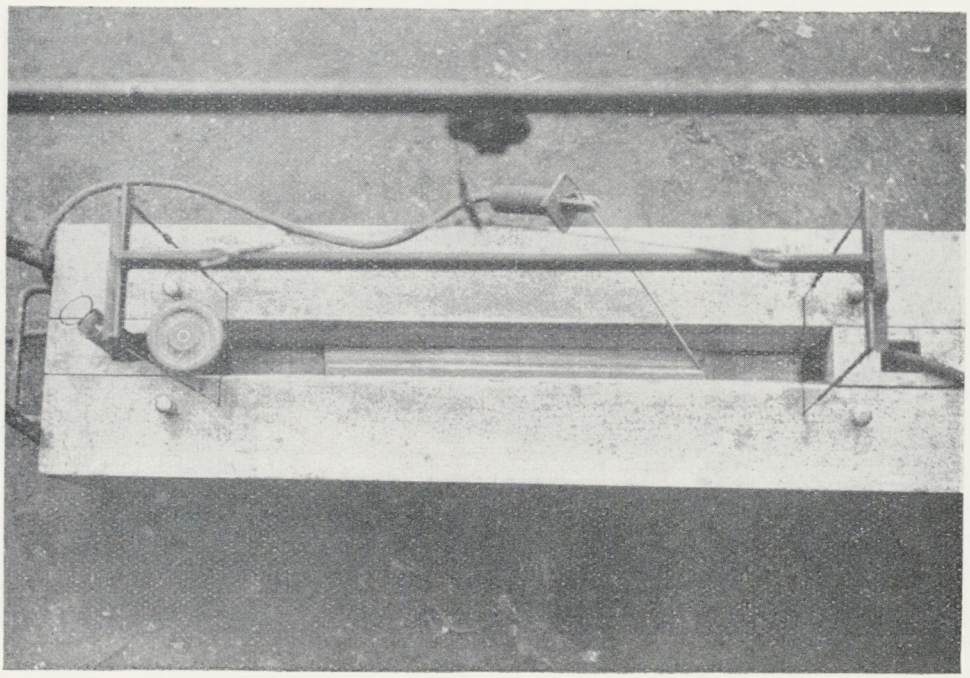
The lower middle range of tests is representative of satisfactory pre-war practice—small to medium gauge electrodes carrying no higher current than is necessary to ensure complete fusion without causing undue heating of the electrode.

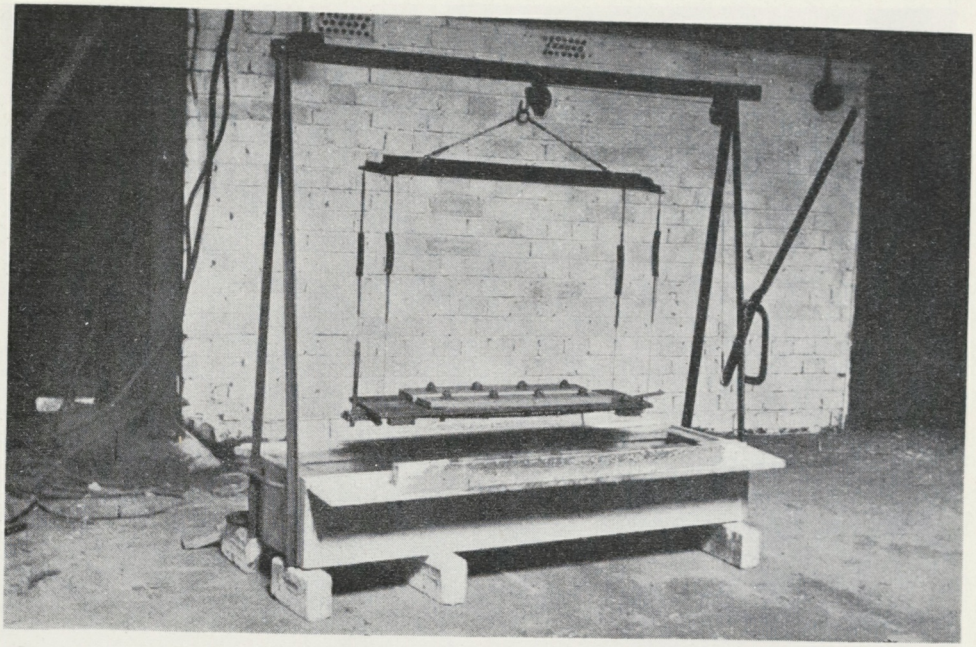
The low stress values for the square-face close butt (2 run) type of joint clearly indicates the particular use of large gauge heavy current welding, combining economy in preparation of joint with all the attributes of a good weld and reasonably free from the influence of high restraint. For low values of residual stress. the choice therefore lies between joints of this type and those which were current practice pre-war.

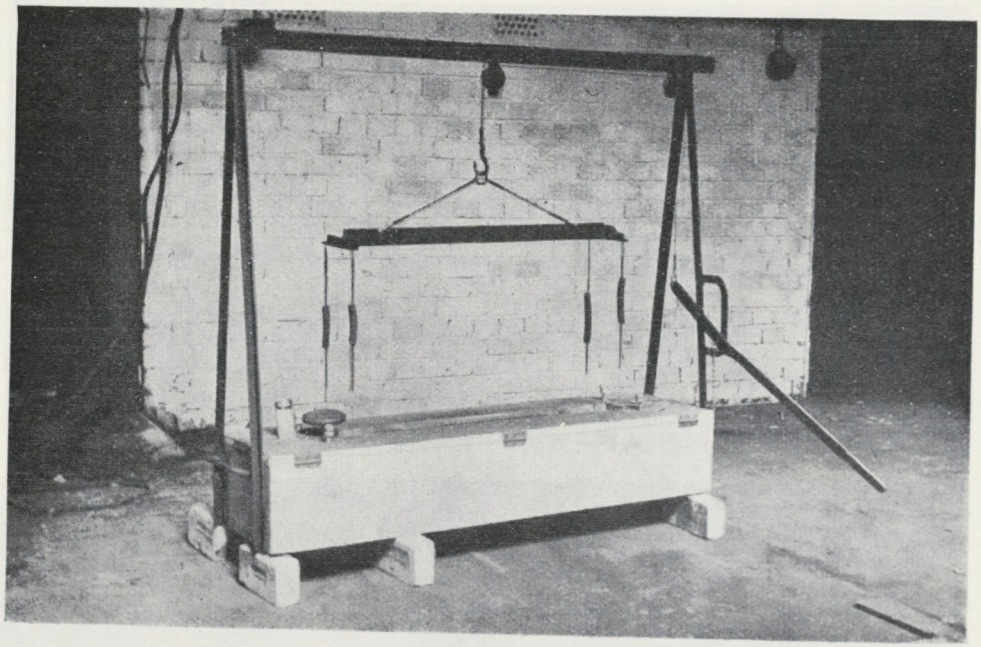












PRELIMINARY TEST.

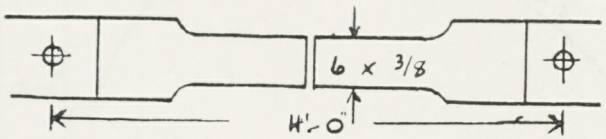
Test 1. To ascertain the average residual stress in an ordinary close fit square face butt weld when the parts are subjected to high degree of restraint. 4 ft. 0 ins. centres.

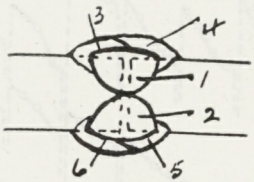
Test 2. To ascertain the increase in average residual stress due to depositing some reinforcement on top of the previous runs—corresponding to excessive deposit of weld metal.

Test 3. To ascertain the effect on average residual stress by chipping off all weld metal down to the flush of the plate.

Test 4. Then to test the weld to destruction.

TEST PIECE.





NOTE :—By error the gap was made $\frac{6}{1000}$ inch instead of $\frac{1}{16}$ inch but it was decided to proceed with the test and to section and etch the specimen to ascertain the depth of penetration.

Test 1. Weld deposits 1 & 2. No. 6 gauge D.P. at 230 amps.

Load for Extension to equal contraction { 28·0 Tons, 28·5 „, 28·0 „ } Mean 28·2 Tons

Average Residual Stress = 12·5 tons per square inch.

Test 2. Weld deposits 3, 4, 5 & 6. No. 6 gauge M.P. at 200 amps.

Load for Extension to equal contraction = 36·0 Tons, 33·2 „, 27·0 „, 27·0 „

Corresponding Average Residual Stress = 16·0 „, 14·7 „, 12·0 „, 12·0 „ } Indicating that stress exceeded the yield point.

Test 3. All welding chipped off to the flush of the plate.

Load for Extension to equal contraction 26·7 Tons, 27·7 „, 27·0 „ } Mean 27·1 Tons

Average residual stress 12·0 tons per sq. inch.

i.e. no reduction in stress by chipping.

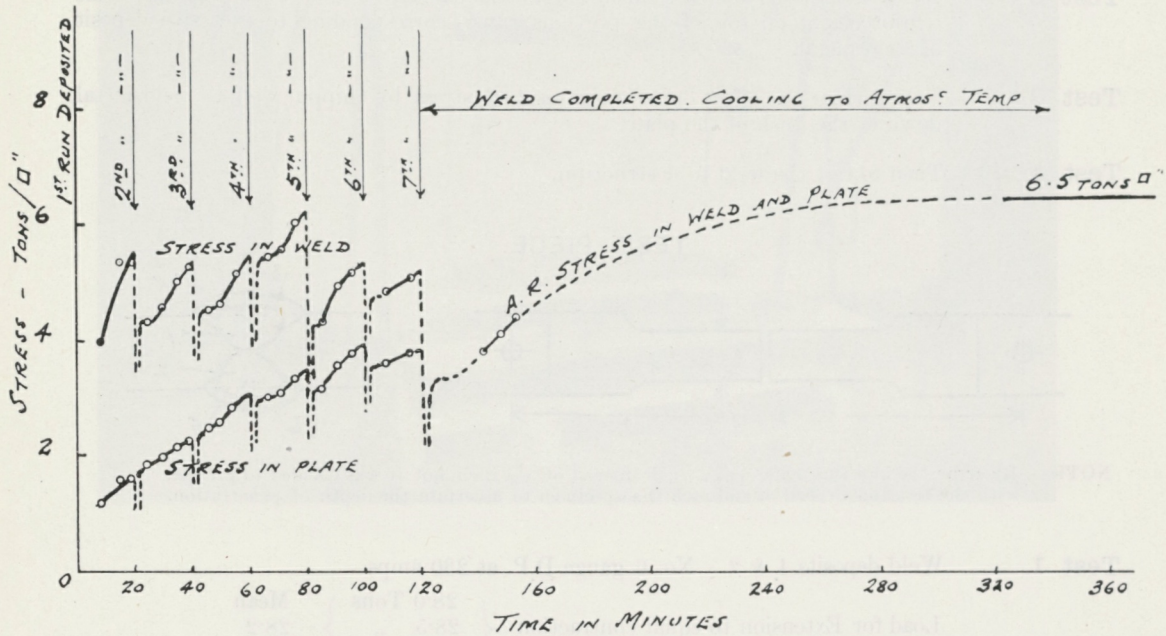
Test 4. Load to break specimen = 54·1 tons.

Corresponding stress = 24·1 tons per sq. inch.

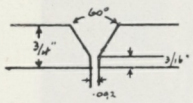
Fractured in weld due to incomplete penetration but equal to 27·8 tons per sq. inch allowing for reduction in area due to incomplete penetration.

WELD TEST No. 3.

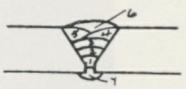
DIAGRAM SHEWING THE PROGRESSION OF STRESS DURING WELDING AND COOLING.



- MEASUREMENT OF RESIDUAL STRESS -



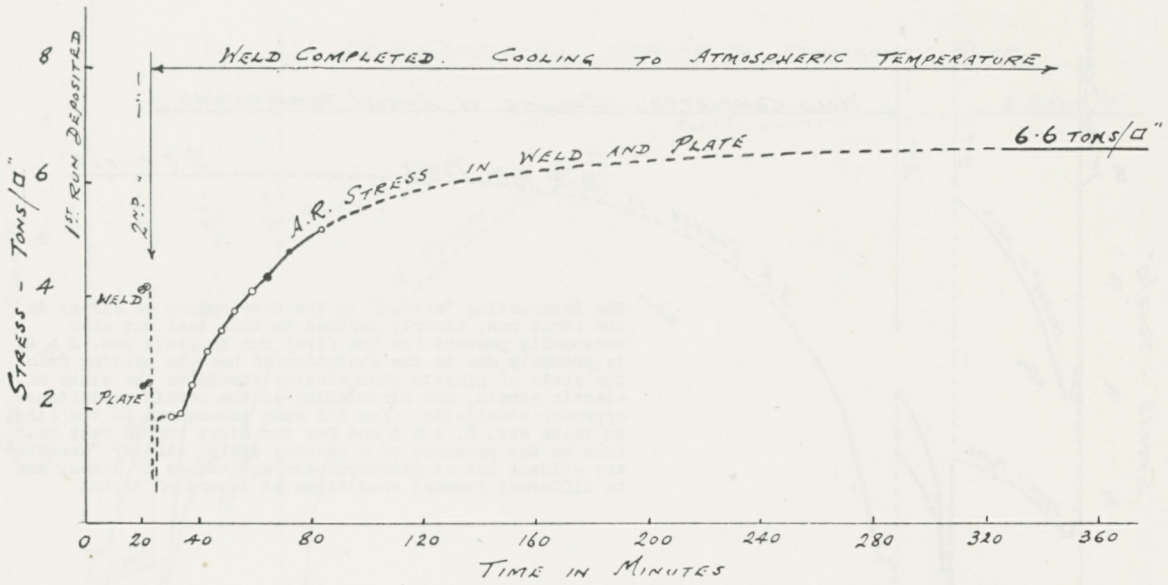
BUTT WELD - Specimen 6" wide x 3/4" thick.
With effective length of 8'0" between centres of restraint i.e. 4'0" each side of weld.
All downhand welding.



RUN No.	Interval between runs	WELD DEPOSIT: ELECTRODE CURRENT: Gauge	Type	AC or DC	Amps.	Volts.	ELECTRODE CONSUMED: Length Ins.	Time secs	Volume Ins.³	Heat Factor Amps.volts.secs / 1000	Weld Section mean depth.	Load for Extn. to equal contraction. Readings taken at	Load required	AVERAGE RESIDUAL STRESS As welded = 87% restraint: Weld	Plate	w/a approximately = 100% restraint: Weld	Plate
1	Mins 20	8	MP	DC	170	25	10¼	60	.206	255	.222	9mins 15 " 19 "	6.1Tons 8.2 " 8.2 "	3.99 5.37 5.37	1.18 1.58 1.58	4.58 6.16 6.16	1.35 1.82 1.82
2	20	6	"	"	210	28	7	50	.203	294	.321	25 " 30 " 35 " 39 "	9.6 10.1 11.2 11.6	4.33 4.57 5.06 5.24	1.85 1.95 2.17 2.24	4.98 5.25 5.82 6.02	2.13 2.25 2.49 2.58
3	20	6	"	"	210	28	8⅝	63	.250	370	.414	46 " 50 " 56 "	12.9 13.2 14.7	4.52 4.62 5.15	2.50 2.55 2.84	5.20 5.32 5.92	2.87 2.93 3.27
4	20	6	"	"	210	28	7⅝	55	.221	323	.414	67 " 71 " 76 "	15.5 15.9 17.2	5.42 5.57 6.02	3.00 3.07 3.33	6.24 6.40 6.92	3.45 3.54 3.83
5	20	6	"	"	210	28	8¼	60	.239	353	.546	86 " 91 " 96 "	16.3 18.4 19.5	4.32 4.88 5.17	3.17 3.56 3.77	4.98 5.62 5.95	3.63 4.09 4.33
6	20	6	"	"	210	28	13¾	95	.384	559	.558	108 " - 117 "	18.6 - 19.5	4.83 - 5.06	3.60 - 3.77	5.56 - 5.82	4.13 - 4.33
6A 7		6	"	"	210	28	11⅝	88	.340	517	.75	142 " 148 " 153 "	19.6 21.2 22.8	3.79 4.10 4.41	3.79 4.10 4.41	4.36 4.72 5.07	4.36 4.72 5.07
									1.843	2671	on complete cooling = 33.7			6.51	6.51	7.49	7.49

WELD TEST No. 4.

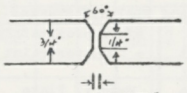
DIAGRAM SHEWING THE PROGRESSION OF STRESS DURING WELDING AND COOLING.



- MEASUREMENT OF RESIDUAL STRESS -

BUTT WELD - Specimen 6" wide x 3/4" thick.

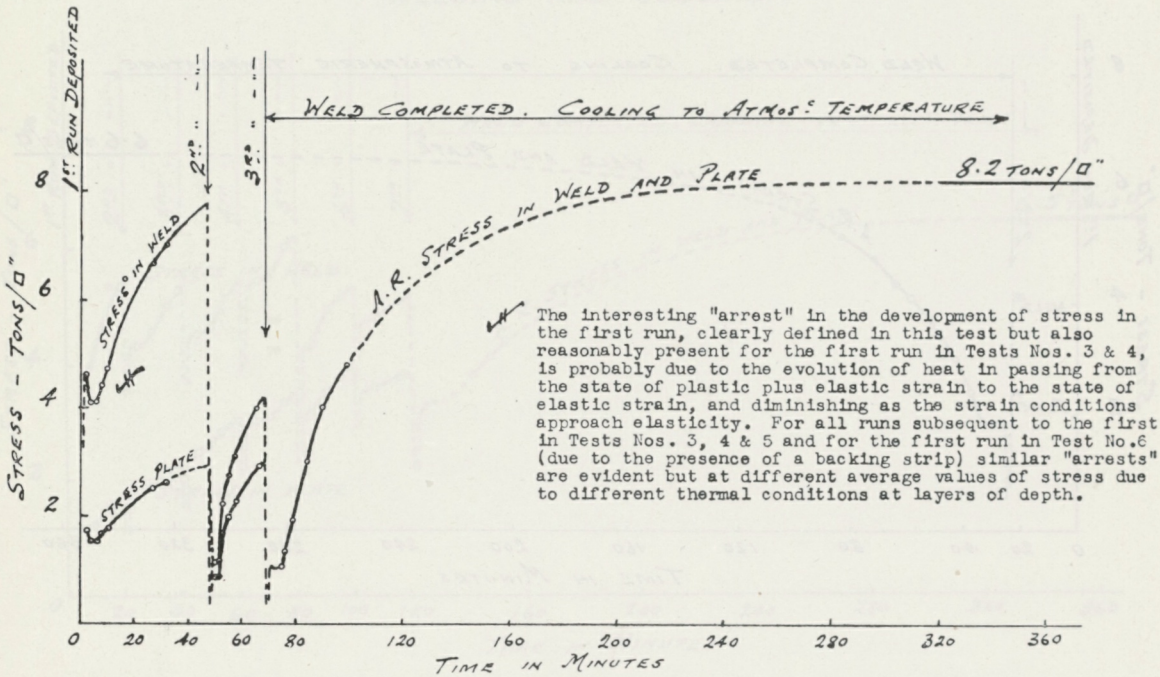
With effective length of 8'0" between centres of restraint i.e. 4'0" each side of weld.
All downhand welding.



RUN NO.	Interval between runs.	WELD DEPOSIT: ELECTRODE CURRENT: Gauge	Type	AC or DC	Amps.	Volts.	ELECTRODE CONSUMED: Length Ins.	Time secs	Volume Ins.³	Heat Factor Amps. volts. secs. / 1000	Weld Section mean depth.	Load for Extn. to equal contraction: Readings taken at	Load required	AVERAGE RESIDUAL STRESS: As welded = 87% restraint: Weld	Plate	w/a approximately = 100% restraint: Weld	Plate
	Mins																
1		5/16	DP	AC	570	57	9 3/4	44	.743	1429	.44	20 Mins.	12.4 Tons	4.08	2.40	4.69	2.76
1a	23	1/4	"	"	350	40	2 3/4	30	.135	420		22 "	12.7 "	4.18	2.46	4.82	2.83
												30 "	9.6 "	1.86	1.86	2.13	2.13
2		5/16	"	"	600	60	7 1/2	38	.575	1368	.75	33 "	9.8 "	1.89	1.89	2.18	2.18
2a		1/4	"	"	260	35	3 3/4	40	.190	364		38 "	12.5 "	2.42	2.42	2.78	2.78
												43 "	15.7 "	3.04	3.04	3.49	3.49
												48 "	17.4 "	3.36	3.36	3.87	3.87
												53 "	19.2 "	3.71	3.71	4.27	4.27
												59 "	21.1 "	4.08	4.09	4.69	4.69
												65 "	22.2 "	4.28	4.28	4.93	4.93
												73 "	24.6 "	4.76	4.76	5.47	5.47
												84 "	26.6 "	5.14	5.14	5.92	5.92
									1.648	3581		On complete cooling =	34.1 "	6.59	6.59	7.58	7.58

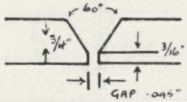
WELD TEST No. 5.

DIAGRAM SHEWING PROGRESSION OF STRESS DURING WELDING AND COOLING.



The interesting "arrest" in the development of stress in the first run, clearly defined in this test but also reasonably present for the first run in Tests Nos. 3 & 4, is probably due to the evolution of heat in passing from the state of plastic plus elastic strain to the state of elastic strain, and diminishing as the strain conditions approach elasticity. For all runs subsequent to the first in Tests Nos. 3, 4 & 5 and for the first run in Test No.6 (due to the presence of a backing strip) similar "arrests" are evident but at different average values of stress due to different thermal conditions at layers of depth.

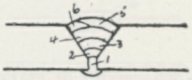
- MEASUREMENT OF RESIDUAL STRESS -



BUTT WELD - Specimen 6" wide x 3/4" thick.

With effective length of 8'0" between centres of restraint i.e. 4'0" each side of weld.

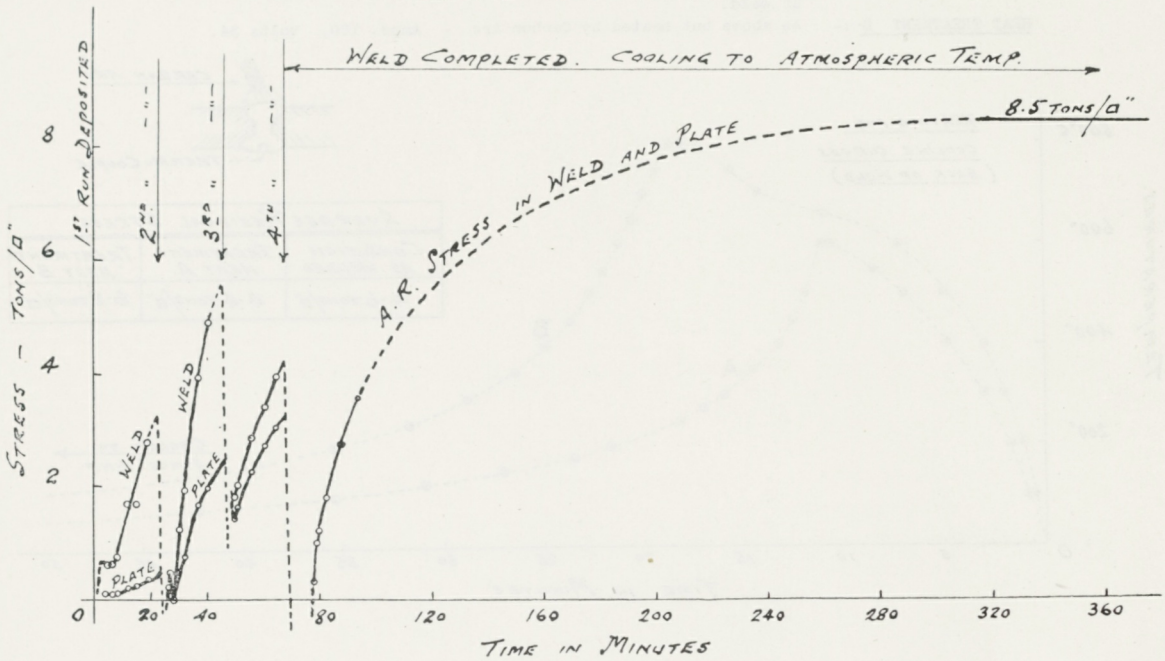
All downhand welding.



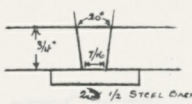
RUN NO.	Interval between runs.	WELD DEPOSIT. ELECTRODE CURRENT Gauge	Type	AC or DC	Amps.	Volts	ELECTRODE CONSUMED Length Ins.	Time secs.	Volume Ins.³	Heat Factor Amps.volts.secs / 1000	Weld Section mean depth.	Load for Extn. to equal contraction: Readings taken at	Load required	AVERAGE RESIDUAL STRESS. As welded = 87% restraint: Weld	Plate	w/a approximately = 100% restraint: Weld	Plate
	Mins											2 Mins	8.9 Tons	4.61	1.72	5.30	1.98
												4 "	7.9 "	4.10	1.53	4.71	1.76
												6 "	7.9 "	4.10	1.53	4.71	1.76
1		5/16	D P	AC	450	53	5½	30	.422	716	.28	8 "	8,5 "	4.42	1.65	5.07	1.89
												10 "	8.7 "	4.51	1.68	5.18	1.93
												17 "	12.4 "	6.42	2.40	7.38	2.76
												27 "	12.8 "	6.63	2.47	7.62	2.84
	47											32 "	13.5 "	7.00	2.61	8.04	3.00
												51 "	4.3 "	1.13	.84	1.30	.96
												52 "	4.4 "	1.16	.85	1.33	.98
2		"	"	"	480	50		30		720		53 "	8.4 "	2.21	1.63	2.54	1.87
							12⅝		.968		.55	55 "	10.2 "	2.69	1.97	3.09	2.27
2a		"	"	"	325	35		40		455		58 "	11.5 "	3.03	2.23	3.48	2.56
	21											66 "	15.1 "	3.98	2.92	4.57	3.36
												75 "	5.4 "	1.04	1.04	1.20	1.20
												76 "	6.8 "	1.32	1.32	1.51	1.51
3		"	"	"	525	45		35		827		79 "	9.8 "	1.90	1.90	2.18	2.18
3a		"	"	"	325	40	17⅞	45	1.371	434	.75	85 "	15.5 "	3.00	3.00	3.45	3.45
3b		"	"	"	310	35		40		585		90 "	20.7 "	4.00	4.00	4.60	4.60
												99 "	24.5 "	4.75	4.75	5.45	5.45
							2.761		3737		On complete cooling =		42.5 "	8.22	8.22	9.45	9.45

WELD TEST No. 6.

DIAGRAM SHEWING PROGRESSION OF STRESS DURING WELDING AND COOLING.



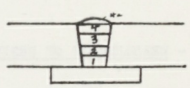
- MEASUREMENT OF RESIDUAL STRESS -



BUTT WELD - Specimen 6" wide x 3/4" thick.

With effective length of 8'0" between centres of restraint i.e. 4'0" each side of weld.

All downhand welding.

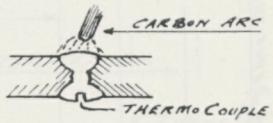


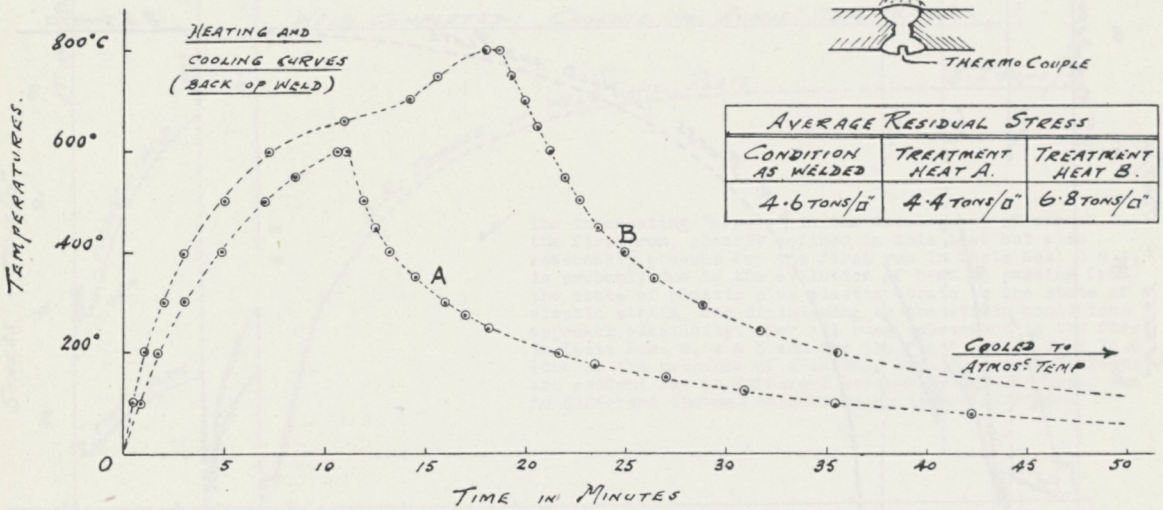
RUN No.	Interval between Runs	WELD DEPOSIT. ELECTRODE CURRENT Gauge	Type	AC or DC	Amps.	Volts	ELECTRODE CONSUMED Length Ins.	Time secs	Volume Ins.³	Heat Factor Amps.volts.secs. / 1000	Weld Section mean depth.	Load for Extn. to equal contraction Readings taken at	Load required	AVERAGE RESIDUAL STRESS As welded = 87% restraint Weld	Plate	w/a approximately = 100% restraint Weld	Plate
												5 Mins	.4 Tons	.62	.08	.71	.09
												6 "	.4 "	.62	.08	.71	.09
												8 "	.5 "	.77	.09	.89	.11
1		5/16	DP	AC	505	48	6¾	31	.518	751	.094	9 "	.4 "	.62	.08	.71	.09
												12 "	1.1 "	1.70	.21	1.95	.24
												15 "	1.1 "	1.70	.21	1.95	.24
	23											19 "	1.8 "	2.78	.35	3.19	.40
												27 "	1.1 "	.51	.21	.59	.24
												28 "	-	-	-	-	-
2		3/8	MP	"	550	37	6	46	.662	936	.312	30 "	2.6 "	1.21	.50	1.39	.58
												33 "	4.1 "	1.91	.79	2.19	.91
												37 "	8.5 "	3.95	1.64	4.54	1.89
	23											41 "	10.2 "	4.75	1.97	5.47	2.27
												50 "	7.4 "	1.81	1.43	2.08	1.64
												51 "	8.2 "	2.01	1.59	2.31	1.83
3		3/8	"	"	580	30	6⅝	49	.705	853	.594	56 "	11.7 "	2.86	2.26	3.29	2.60
												61 "	14.0 "	3.42	2.71	3.93	3.11
	22											65 "	16.1 "	3.94	3.11	4.52	3.58
												78 "	1.5 "	.29	.29	.33	.33
												79 "	5.2 "	1.01	1.01	1.15	1.15
4		3/8	"	"	500	47	5½	39	.607	916	.75	80 "	6.2 "	1.20	1.20	1.38	1.38
												83 "	9.4 "	1.82	1.82	2.09	2.09
4a		"	"	"	400	32	7	61	.773	781		88 "	14.3 "	2.76	2.76	3.18	3.18
												94 "	18.5 "	3.58	3.58	4.12	4.12
							3.265			4237		on complete cooling =	44.0 "	8.51	8.51	9.78	9.78

WELD TEST No. 13.

HEAT TREATMENT A :- Weld section heated by Carbon Arc - Amps: 130/140, Volts 30. Temperatures taken by thermo-couple thermometer clamped to back of weld.

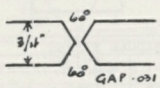
HEAT TREATMENT B :- As above but heated by Carbon Arc - Amps. 160, Volts 34.





AVERAGE RESIDUAL STRESS		
CONDITION AS WELDED	TREATMENT HEAT A.	TREATMENT HEAT B.
4·6 TONS/□"	4·4 TONS/□"	6·8 TONS/□"

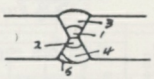
- MEASUREMENT OF RESIDUAL STRESS.-



Butt Weld - Specimen 6" wide x 3/4" thick.

With effective length of 8'0" between centres of restraint I.e. 4'0" each side of weld.

All downhand welding.



RUN NO.	Interval between runs	WELD DEPOSIT. ELECTRODE Gauge	ELECTRODE Type	CURRENT AC or DC	CURRENT Amps	CURRENT Volts	ELECTRODE CONSUMED Length Ins.	ELECTRODE CONSUMED Time secs	ELECTRODE CONSUMED Volume $Ins.^3$	ELECTRODE CONSUMED Heat Factor Amps.Volts.secs. 1000	Load for Extension to equal contraction Tons	AVERAGE RESIDUAL STRESS. As welded = 87% restraint Weld	As welded = 87% restraint Plate	w/a approximately = 100% restraint Weld	w/a approximately = 100% restraint Plate
1	15	10	D.P.	AC	132	35	9¾	34	.125	157					
2	15	10	"	"	135	35	14⅛	53	.187	250					
3	15	6	M.P.	"	228	22	10½	68	.297	341	20.6, 21.0, 20.6 } Mean 20.73	4.00	4.00	4.60	4.60
4	5	6	"	"	232	22	10⅛	70	.304	357					
5	-	6	"	"	232	22	1⅜	10	.051	51					
									.964	1156					

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DISCUSSION AND AUTHORS' REPLIES

on

SHIP WELDING AND THE INFLUENCE OF RESIDUAL STRESSES

By

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DISCUSSION AND AUTHORS' REPLIES

on

SHIP WELDING AND THE INFLUENCE OF RESIDUAL STRESSES.

MR. J. M. MURRAY.

THIS is a very important paper; it is the first occasion on which the results of experiments made by Surveyors have been communicated to this Association. Generally speaking the papers read to this Association deal with the broader aspects of shipbuilding and marine engineering, and embody the experience of the authors on certain aspects of these sciences; they do not, in general, represent the results of detailed investigations into a specific problem. A feature of modern research is that it is now to a large extent conducted on a co-operative basis and, while it is proper and necessary that this should be so, it would be unfortunate if the individual investigator were to assume that the importance of his work is lessened thereby. The authors state that if the spirit of independent inquiry had never been fostered many a revealing fact and opinion would not have been disclosed, and it is opportune that this view should be expressed at the present time. The work of the individual experimenter must be complimentary to that of the large-scale research associations, but if it is not available then research as a whole will be much the poorer. It is hoped that this Association will receive more papers of the kind presented by Messrs. Stocks and Thurston.

It is not intended to discuss here the details of the problem of residual stresses or to comment on the absolute values determined by the authors; no doubt this aspect of the matter will receive adequate consideration by other contributors to the discussion. The writer will confine himself to one or two points of detail. In the first place it might be mentioned that the figure of 87 per cent restraint, for which the apparatus has been designed, must excite comment. The justification for this factor given on page 9, can hardly be taken as being a general application, and in investigations of this kind it is the general rather than the particular which is important. Apart altogether from the difficult question of the actual restraint, it would have been more suitable to design the apparatus so that the constraint was a round figure, say, 80 per cent, 90 per cent, or even 85 per cent, but 87 per cent argues a precision which certainly does not arise in practice.

The method in which the results are summarised in Diagram 4 is open to objection. The particulars used in the preparation of this diagram are obtained from a series of experiments where the length of the specimen was 8 feet and the breadth 6 inches throughout, and, therefore, it is not legitimate to plot the results on the basis of a parameter which includes the length and breadth of the specimen, characteristics which are, in fact, constant for the data in question. It is probable that the use of the parameter L might well be justified although, as will be pointed out later on, there are some doubts about that, but it is considered that the use of the parameter small "l" cannot be allowed. If the breadth of the specimens were increased it is likely that entirely different results might be obtained.

An examination of the spots on Diagram 4 shows that instead of drawing one comprehensive curve as has been done, it is possible to draw a family of curves through the spots representing a particular type of edge preparation. These curves will be less acutely inclined to the base than the curve drawn, and one implication of this is that stress does not vary inversely with

the length of specimen. The data given refer to a specific set of experiments, and it is unfortunate that the implication is made that these results may be applied in a general sense. Nevertheless, this criticism does not invalidate the general value of the paper.

MR. J. S. ORMISTON.

Firstly, one can endorse heartily the statement on page 2 "that high ductility is an essential requirement for weld metal." It has always been my opinion that in headlines of advertisements for electrodes high ductility should come first and in priority to "ultimate strength equal to that of parent metal."

The authors use the term residual stress—on page 5 of paper— to cover restraint, but it is suggested a clearer notion of the state of things in a welded structure is obtained by classifying straining due to restraint separately under the heading reaction stresses, because so-called residual or shrinkage stresses arise from thermal disturbances set up, and are basically due to the fact that our constructional material has a natural coefficient of expansion or contraction. We have such stresses in the simplest imaginable welding operation, namely an ordinary butt-weld joint between two pieces of plate without external restraint. Stresses are induced parallel to and normal to the centre line of the weld arising from shrinkage of the deposited metal and adjacent parent metal being resisted by the cooler metal more distant from the material which was temporarily in a plastic condition. In general, these stresses are tensile at the weld, this tension gradually decreasing until we enter a zone of compression as we go towards the plate edges; these zones of unlike strain are in equilibrium. This phenomenon is not included in the relatively narrow test pieces used by the authors for obvious reasons.

Had the two plates referred to been clamped rigidly during welding, additional tensile stresses, that is reaction stresses, would have been set up, thus compressive stresses induced in the "free" welding operation might be reduced to zero, while those in tension would have this state increased.

In visualising all this we have to bear in mind that while the weld metal and parent metal very near to it are at temperatures above 500 degrees or 600 degrees their yield and ultimate strength values are very low indeed, and plastic yield can take place—moreover Young's modulus is less than for metal at ordinary room temperature.

Indeed, my impression is that the salvation of the matter lies in plastic yield accompanied by moderate strain-hardening, coupled with the flexibility of the ship structure.

As a matter of interest relevant to the authors' remarks on page 5 and sketch on page 9 of the paper might be mentioned that in order to reduce the rise of bottom of ship which took place in the earliest of the Ocean class ships building at Portland, Maine, U.S.A., the remaining ships of this programme built at this yard were built in three sections—a slip joint, so to speak, was arranged at about one-fifth vessel's length from each end. The three parts were welded up to each other—butts and seams—after practically all the welding of each part was completed, and so the rise of the bottom at the end of the ship due to shrinkage previously experienced was practically eliminated and so far no trouble appears to have arisen from this procedure. Also it removed inconveniences for the engineers in operations of lining up the shafting.

In conclusion, I must say I feel personally that a responsible constructor would always be wise to adopt and maintain a well-tried sequence in welding up a ship, as for example, welding butts from amidships towards each end of the ship so that the most restrained joints are not in parts of the ship subject to the greatest structural stresses. Moreover, if welding leads a designer to the careful elimination of the objectional discontinuities which have been not unknown in riveted ship structures, a great service in this direction will have been effected.

MR. F. C. COCKS.

This problem of residual stress has been present and fully appreciated ever since the inception of electric welding. It has not yet been completely solved, but it has been the subject of a considerable amount of research both before

and since the failures of some of the American all-welded ships. When these unexpected and, therefore, spectacular failures occurred, and an inquiry was called to investigate their cause, it was not altogether surprising that attention was for a time focussed on the possible influence of residual stress. It became something of a bogey, especially in the minds of those who had previously been oblivious of its existence, but gradually receded into its correct perspective as a result of intensive study and experiment.

Briefly stated, two main conclusions were arrived at, namely :—

1. That almost any weld, in the as-welded condition, will give rise to residual stresses adjacent to the weld equal to the yield point of the parent metal or the weld deposit, whichever is the lower.

2. That, so far as test specimens are concerned, under static, fatigue or impact loading, the presence of thermal residual stress has little effect on the ultimate result.

In a welded structure, however, conditions are not so generally favourable as in a test specimen, and so other factors must be taken into account, such as discontinuities inherent in the design or caused by faults in the welds, both or either of which may form sources of initiation to fracture. It is in association with these latter that residual stresses may become potentially dangerous.

Also in an all-welded structure, which is, compared with its riveted counterpart, monolithic, a fracture once initiated will more often than not propagate much further, sometimes with catastrophic results.

It is, therefore, of the utmost importance, while accepting that residual stresses are present of the order indicated above, that discontinuities of every kind shall be avoided if possible, and this can only be done by good design and careful attention to welding technique.

Peaks of residual stress can be avoided by correct sequence, limiting welds to the least size compatible with the necessary strength, welding joints which cause most contraction first, and depositing the greatest amount of weld metal in the shortest time. Relief can be gained in particular cases by pre-stressing, pre-heating or by peening, and lately there has been introduced in some shipyards in America a system of controlled low temperature heat-relief, in which the material adjacent to the joint is heated by travelling gas burners and afterwards quenched with water.

There is a common feature in all the cases of failure to the American ships which leads one to the conclusion that residual stress, per se, was not the cause of the failures, as the authors of the paper would seem to suggest. Take two particular examples, perhaps the most notable because they were among the first, and occurred without warning and without reasonable expectation. The fracture resulting in the "jack knifing" of the tanker "SCHENECTADY" was found to have originated in a defect in the welded attachment of the upper deck stringer plate to the sheerstrake. The effect of this was accentuated by its proximity to an undesirable notch formed where the after fashion plate of the bridge terminated on and was welded to the top edge of the sheerstrake.

The "ESSO MANHATTAN" broke in two in a calm sea while ballasting outside harbour, and it was stated that owing to trouble with valves, the specified scheme of ballasting was not adhered to. Here examination showed that the fracture started in defects in a butt-weld between two plates in the centre strake of upper deck plating, and ran, not through the stressed material adjacent to and parallel with the joint, but obliquely at 45 degrees across the deck. In all or most cases, investigation has proved that fractures have originated at sharp discontinuities either in the structure as designed or in the welds. Residual stresses must have been present in other parts of the vessel, but fracture took place at a notch. The inference from this is that whereas residual stress can rarely be eradicated, and only by special treatment, its influence can be discounted provided due attention is paid to design, and care taken with workmanship to eliminate or avoid notches.

On the question of the effect of size of electrode, welding current and speed of welding on shrinkage, a great deal of experiment has been

carried out, especially in recent years. Griffith, in the U.S.A. in 1941, showed that in welding a butt in $\frac{5}{8}$ inch mild steel plate, the greatest residual stresses set up at right angles to the weld occurred when very small electrodes were used, and that not only were the peak stresses lower with high currents but a more uniform distribution of stress resulted. He used the sub-division method of measuring relaxation, and deduced the stresses from the release of strain.

Recent research at Cambridge bears out the foregoing conclusion.

Quite apart from considerations of stress and even of economy, it is my opinion that many of the defects which frequently occur in welds would be reduced by the use of large electrodes bearing high currents. Fewer runs make for a lower liability to slag inclusions, high current promotes better fusion, and higher speeds result in a lower heat input and a reduction in shrinkage and distortion. With the use of small electrodes, on the other hand, there is present, in addition to the possibility of slag inclusions and lack of penetration and fusion, the danger of a crack developing in the first run, especially when welding under restraint.

The experiments which the authors describe represent a considerable amount of painstaking work with a notable attention to detail. I will leave to others to argue about the premises on which the criterion of restraint have been based. On this matter I only want to make one observation. The authors have assumed a constant degree of restraint throughout the welding of the joint, whereas so soon as the first run has been started and the weld metal cooled, the restraint is very considerably increased. They have also measured the average stress induced over the length and breadth of the specimen, whereas the stress is by no means uniform. Too much stress should not be laid on the results obtained. With so many variables, of which not the least is the human factor governing the quality of the manual weld, and which may have a significant effect on results obtained from test specimens of limited width, it would be unwise to generalise from such results. Their treatment of the problem should, however, afford an interesting comparison with similar work in which other methods of measuring reaction stresses were employed.

If the paper does no more than stimulate inquiry into the subject under review, and indicate the necessity for a close attention to design for welding and a high standard of workmanship and supervision, then it will have served a most useful purpose, and one for which the thanks of the Association are due to the authors.

MR. R. GIBBS.

The authors discuss at length the spectacular failures of the all-welded ship built during the war, but so far as I know there were no spectacular failures of all-welded ships built during the pre-war years, when building speeds were slower and every opportunity was taken to ensure good workmanship. They state that "we can ill blame the material if it fails to respond to exceptional treatment." Surely the "exceptional treatment" referred to comes under one of the headings of workmanship, and there is no doubt in my mind that such treatment, which in many cases could be classified as brutal, was a contributory cause of failures, and I am of the opinion, despite the statement on page 5, "that workmanship was ever improving" that the reverse was the case, and that the quality of work deteriorated rapidly during the war period.

A large influx of green labour into the yards, all to be rather sketchily trained, a shortage of proper supervision both by shipyard and inspection personnel, and that bug-bear of good workmanship, piece work, all had their evil effect, and in the majority of failures which occurred, poor workmanship was found to be an important contributory factor.

The first 10 post-war ships built by the Sun S.B. & D.D. Co. at Chester, Pa., were classed by the Society, and it was immediately found that the transition period between what was good enough during the war and the post-war standard of workmanship required both by the Society and the shipbuilders themselves was an extremely difficult one. The Sun Yard is an old-established one with a nucleus of craftsmen in its employ, and it was fully impressed on my mind how serious the situation must have been in some of the newer yards where almost 100 per cent of the

labour and most of the supervision were totally inexperienced. To me, the marvel is that considerably more vessels did not suffer spectacular failure.

The authors lay particular stress on an ever-present tendency to widen the gap when using large electrodes, but, in my experience, good practice demands that in order to effect proper penetration the first run of a multi-pass butt weld should be made with a small rod in conjunction with a manual root opening of $\frac{1}{8}$ inch or $\frac{3}{16}$ inch, depending on the thickness of the material, and I should be glad to be enlightened on this point.

MR. JAROSZYNSKI.

The problem of residual stresses is a very complex one, and although a considerable amount of work has been carried out in that field, we are not in a position at present to ascertain the magnitude of stresses which, irrespective of technique and sequence of welding, will be set up in the structure.

The magnitude of residual stresses is affected by so many variable factors that in any experiment it is not possible to allow for all of those at the same time. For this reason the conditions of test do not simulate the practical conditions —as has been remarked by the authors—and, therefore, when examining the results of the experiment, it must be borne in mind that they cannot be used directly to predict the stress which will be set up in the ship's structure.

On page 2, the authors have quoted two factors which result in a high value of residual stress. With reference to the first one, namely, high restraint due to large size of prefabricated assemblies, have the authors any comment to offer on the fact that in the U.S.A. Swan Island Shipyard, Portland, Oregon, has developed an "end-to-middle" sequence of welding ships' structure in which the hull is divided into three separate parts on which work is carried out simultaneously and sections are joined together when the hull is nearing completion? This method has been developed for the construction of large 520 feet turbo-electric tankers for the Maritime Commission. The builders claim that although this method represents a radical departure from the conventional one adopted in the Liberty programme, there were no fractures in the ship's structure after a period of service, which could be traced to this revised welding sequence. It is also known that German submarines have been built in sections and joined together by circumferential welds. This circumferential weld was not commenced at the neutral axis and worked progressively towards the top and bottom, but eight welders, placed around the perimeter were carrying on work simultaneously which enabled the weld to be completed in one day. Such a method of joining large pre-assemblies offers great advantages, and it may be expected that future development will tend to be on similar lines.

The second factor which tends to produce high residual stress is termed by the authors high "heat input." Perhaps this could be more explicitly expressed as the amount of metal deposited. Welding is, in principle, a miniature casting operation in which molten metal provided by the electrode is filling the gap between two members to be joined together. The greater the amount of deposited metal, the greater contraction and resulting stress.

Examining the test results on page 14, I have calculated the heat input per unit volume of electrode used and found that it has been more or less uniform throughout the series, being higher for tests Nos. 11, 15 and 17. However, tests Nos. 4 and 10 show considerable departure from the other tests—the value of heat input per unit volume being 2,175 and 683 respectively. Could the authors give any explanation to this discrepancy?

I have also related the volume of the electrode used for the sectional area of the gap by dividing one by the other. Here again, test No. 4 doesn't line up with the others—the amount of electrode consumed being approximately four times the volume of the gap to be filled, which cannot be explained by the reinforcement of the weld.

The diagram 4 on page 15, showing the results of the experiment, the residual stresses obtained, tests Nos. 6, 5 and 2 are placed on the straight line, but excess of deposited material over the

value of the gap is 28, 82 and 48 per cent respectively. In view of such discrepancies, could the authors explain why they have made the amount of electrode deposited, as a parameter, and why they have chosen this particular base for plotting the results of experiments?

Results of test No. 13, on page 24, are not surprising. Heating of the weld alone did not relieve, but in test B, even increased the residual stress. With reference to this test, it is worth mentioning the method of relieving residual stress developed by the Lindey Air Product Company of New York which has been adopted and claimed to be successful on the American Maritime Commission T2 tanker built in the Sun Yard, Chester. This method is based on the principle that residual stresses are due to the relative difference in length between the plate material and cooled weld metal and that release can be accomplished by changing the relative length between those two. If, on applying heat, the plate material adjacent to the weld could be expanded lengthwise by an amount corresponding to the yield strain in the weld when the weld metal would be kept at normal temperature, the weld metal would be stretched by an amount equal to the expansion. This stretch on the deposited metal would be plastic and would not be regained when the heated material returns to its normal length on cooling.

MR. G. M. BOYD.

With regard to the first part of the paper, in which the authors ascribe the fractures in welded ships to residual stresses resulting from the adoption of large sub-assemblies, large electrodes, and high welding currents, they differ strongly with the results of extensive research work in this country and America. Part of the British conclusions in this respect are quoted on page 1 of the paper, and the American counterpart is given in the official announcement of the final report of the Board to Investigate the Design and Construction of Welded Merchant Vessels in *The Welding Journal* of June, 1947, from which I quote the following passage:—

> "Although a large amount of work has been accomplished in the investigation of residual and locked-in stresses, resulting in a considerable extension of knowledge in this respect, no evidence has been found to indicate that these stresses are important in causing fractures in welded ships."

Anyone, therefore, who wishes to form his own opinion on the matter would be well advised to read the present paper in conjunction with the extensive published reports of other workers in the same field.

The use of the term "Degree of Restraint," expressed as a percentage, perhaps requires some elucidation. As used in the paper, the term "87 per cent restraint" simply means that with the particular specimens used, the force required to close a given gap in the specimen, or the force generated by a given weld contraction, was 87 per cent of the force which would have been generated if the restraining structure were infinitely rigid. It must, however, be remembered that even if the restraining structure were infinitely rigid, the specimen itself is elastic, and, therefore, the restraint could be increased or decreased by reducing or increasing the length of the specimen, without altering the quality which the authors have termed the "Degree of Restraint." This can be shown by putting the "Degree of Restraint" equal to unity in the expression for "P" on page 9, which then becomes:—

$$P = \frac{dE}{L}$$

so that the stress P is inversely proportional to the length L, which does not figure in the expression which has been called the "Degree of Restraint." This expression is, therefore, not truly representative. A more correct index of the restraint would be the force (or stress) required to close unit gap, or generated by unit weld contraction. This would be expressed by:—

$$R = \frac{E}{L}\left(\frac{1}{1 + \frac{a}{A} + \frac{a y^2}{I}}\right)$$

which has the dimensions of a stress per unit length of specimen.

The figure 87 per cent has, therefore, only a limited meaning in connection with the particular test rig, and this remark applies equally to any other such percentage, including 100 per cent.

The fact that the results have been presented in terms of "100 per cent" restraint, does not render them any more generally applicable or comparable than if 87 per cent, or any other arbitrary percentage were adopted.

This point is of great importance in interpreting the experimental results, particularly in view of the implication that the restraint in the case of the ship example cited, is the same as that in the test apparatus. The ship calculation does not include the length of the "specimen," and is, therefore, invalid.

As other speakers have remarked, the width of the specimen has a profound influence on the value of the reaction stress produced by a given welding procedure. This influence is so great that it may well reverse the order of merit (in terms of reaction stress) of any two procedures. Further, a narrow specimen can give no information on the effects of sequences, such as "step-back" and "block" sequences, which are known to affect the reaction stresses profoundly. Investigations on large sub-assemblies and on actual ships, carried out with great care at the University of California, have shown that the residual stresses remote from welds are small, and usually compressive, while the residual stresses in the vicinity of the welds are always up to the yield-point in tension, regardless of the procedure or sequence used.

MR. F. BROOK SMITH.

The authors stated that (*a*) every welded structure (unless stress relieved) contains local locked-up stresses, this is followed by (*b*) provided the material including the weld can behave in a normal ductile manner the locked-up stresses do not impair the strength of the ship's structure.

It is difficult to understand how it is possible to have a structure containing locked-up stresses and at the same time expect it to continue to behave in a normal ductile manner.

Following this it is stated that investigations have shown that steel in some cases, from other sources than British manufacture, is liable to fracture in a brittle manner. One would like a little elaboration on this as it is concluded that ship steel is invariably subjected to the accepted tests before being used.

The authors quote from the Admiralty Ship Welding Committee's deliberations as follows: "that welding as a process for building ships has been entirely vindicated. Given sound design, good workmanship and tough steel, the reliability of welded ships is beyond question." It is with a great deal of hesitation that a mere mortal dares to question any statement of fact by this august body. At the same time it appears that either sound design, good workmanship and/or tough steel is lacking in several otherwise high-class vessels, as evidenced by the drastic alterations being made to a number of fast American-built all-welded oil tankers. It has been found necessary in these cases to cut the deck and shell plating and to fit heavy longitudinal riveted straps. The deck plating is cut on port and starboard side, the shell in two places on each side, and the bottom shell plating on port and starboard sides. The deck and bottom shell straps have four rows of rivets and the side shell plating six rows. The straps are practically three quarters the length of the vessel. In addition to the foregoing all seams and butts of deck and shell plating were low-temperature stress relieved.

It will be of interest to learn how all this conforms with the conclusions previously referred to that "the reliability of welded ships is beyond question." Maybe it has to be assumed that in these instances the design was unsound, the workmanship not good or the steel not tough.

It has been stated that with all welded vessels underwriters are particularly interested to know if straps have been fitted, but this cannot be confirmed, and perhaps the authors can give some information on the subject.

On page 3, column 1, paragraph 2, the authors make a statement which has, in my opinion, a bearing on the disquieting failures they refer to in their following paragraph, i.e., "workmanship might be described as good, the best obtainable under shipyard conditions, no comparison is possible with the standard of workmanship attainable under the ideal conditions of a workshop." In too many cases it is feared the workmanship might *not* be described as good. It is comparatively easy to test a riveted connection, the riveter is aware of this; generally he has been trained in a hard school and learned to make a

good job. A number of rivets having to be cut out and renewed lowers his pay packet when on piecework rate. The welded connection is not easy to test, the welder is aware of this, and he has not learned his job in a hard school. He, also, is generally on piecework rate, and at times is not above doing what he knows full well is wrong. As an instance, the writer visiting a vessel during a meal-time break, came across a deck plate butt having an electrode laid in the vee and partly welded. The object in this instance being to enable the welder to increase the amount of run of welding done during the day. When this was brought to the notice of the management surprise was expressed, as the welder was considered to be one of their best. Maybe the authors will content themselves by saying this is an exceptional experience and that with proper supervision should not have occurred; it probably is not an exceptional practice, and as for proper supervision it can only be said that this is best attainable under the ideal conditions of a workshop, where all the tests governing methods of procedure, etc., are utilised. The authors carried out all their tests under workshop conditions and the results obtained are probably better than could be attained under other conditions, which would not give the low stress values it is desired to plan for.

It would be of interest to learn whether the authors are in full agreement that welding as a process for building ships, under existing shipyard conditions and without any temperature stress relieving, given the three attributes previously referred to, viz: sound design, good workmanship and tough steel, is equal to an all or part riveted vessel and that welding as a process for building ships of all classes has been entirely vindicated?

Since writing the foregoing, a stop-press item in one of the national daily papers quotes the interception of an S O S reporting an all-welded vessel had broken in two. Surely this is food for thought!!

MR. G. T. CHAMPNESS.

I do not propose to add anything to the discussion on the question of residual stresses in welds, as that subject is well catered for in available technical literature.

I am only concerned now of considering whether one can apply the results of the authors' tests to the daily question of repairs by welding.

Despite its title, the paper may well draw one's attention away from the complexity of stresses in and adjacent to the weld metal, to a consideration of how welding technique may affect the loading of the structure that has to be repaired.

Putting the matter baldly, the authors' tests indicate values for the restraining load or superimposed load resulting from contraction stresses in welds made in a 6 inch by $\frac{3}{4}$ inch section, under various specific conditions.

The point that now arises is whether the test results can be held to apply in some measure to conditions of repair work that differ from those obtaining in the tests, or, put in another way, whether they shall affect our common practice of 70 degrees V, $\frac{1}{8}$ inch gap, 180 amps, and so forth, according to plate thickness. On the face of it, the test data appears to have no general application. Firstly, the expression for the base of diagram 4 is an empirical one chosen to suit the test figures, although I do not recollect in the paper the statement that the reduction of dimension L by one half would result in residual stress of the order of twice the given figure.

Secondly, however interesting the conclusions to be drawn from the square butt joint may be, the fact remains that even if one could persuade the average repair yard welder to use 480 amps with a $\frac{5}{16}$ inch rod, the chances of his obtaining full penetration would be remote with this type of preparation.

Additional complication arises when, as so often occurs in practice, a welding sequence has to be adopted in order to minimise distortion, and finally, if thicker plates are considered, I have found from investigations in connection with peening technique that there is a limiting depth of deposited weld metal upon which additional runs produce no further measurable contraction normal to the run; that is to say, contraction load is not proportional to the volume of weld metal deposited.

I realise that the paper has not been presented to encourage discussion on welding technique, but the test figures are bound to make one reflect

upon superimposed stresses as a corollary to residual stresses, and the authors might be good enough to tell us whether their findings have any general application as distinct from specific test conditions.

MR. A. REID.

From an examination of the equations in the left-hand column of page 10 it is evident that Young's Modulus for the material of the welded specimen is the same as that for the test apparatus, both specimen and apparatus being presumably made of mild steel of Lloyd's Register quality. I should be glad, however, if the authors clearly stated that mild steel is the material.

The authors in their equations have taken into account only the specimen and the main frame of the test apparatus. It does seem from an examination of the drawings of the apparatus that the results would be affected by the area and strength in compression or shear of the pins transferring the load from the specimen to the apparatus. If the frame were perfectly rigid and the pins were elastic and very soft or very thin the locked-up load in the specimen after cooling and contraction of the weld could be quite small, practically all the yield taking place in the pins themselves. But to bring the apparatus back to the condition where the pins are free to rotate might require a very large force whose magnitude would depend on the cross sectional area and Young's Modulus of the specimen, because now the specimen is being strained to an amount practically equal to the yield of the pins. This is, of course, an extreme case; but I should appreciate the authors' comments on the effect of this point on their results.

I should be glad to know, too, if the ends of the welds were ground flush with the sides of the specimen before tests were made.

MR. T. P. GIBBESON.

As the title of the paper implies, the main theme relates to residual stresses. As a matter of interest I would like to mention another viewpoint which certainly plays a big part in determining whether the weld is going to be sound or otherwise, and that is the human element. A certain proportion of the welding can be done by mechanical means, but the greater part in ship construction has to be done by hand. On outside work a welder may often have to work in damp and cold conditions which without a doubt do not assist in obtaining the best results. Of course, this can be obviated to a great extent by prefabricating sections under cover, leaving only the final assembly to be welded together in the open.

A case comes to my mind when visiting a boiler works on Clydeside. A rectified fuel oil tank for a motor vessel was in the course of prefabrication in the shop. On putting my head through the manhole to see how the work was progressing, I was choked by the fumes from the electrode, and I wondered to myself how on earth the welder was able to carry out his duties satisfactorily under these conditions. The air inside the tank could very easily have been kept pure by the simple expedient of leaving a cover off on the top and by having a small fan to circulate clean air inside. I later had to witness an hydraulic test on this tank, the pressure being only about 10 lbs. per square inch, and I was not surprised to find that there were leakages at several places round the seams.

Summing up—if a little more thought was given to the conditions under which a welder has to work, the efficiency of the welds would be greatly improved.

MR. T. F. NAISBY.

It is suggested that equation (1), page 8, should read

$$d - \frac{p\ (L - d)}{E}$$

It is realised that since d is small compared with L the authors most probably made the approximation intentionally, but it is thought the fact should be mentioned, since such approximation applies only to the tension member (specimen) and not to the restrainer, and the deflections of these two have been equated.

MR. H. V. CAMPBELL.

In repair work one often finds the tendency to leave gaps much too wide, whether in butt joints of plates or veed-out cracks, and the oft-repeated injunction to keep the gap or vee to a

minimum consistent with good penetration is justified by the findings of the authors' investigation. Again—guidance is given regarding the desirable minimum length of shell plate (say) to be cropped, renewed and butt-welded to insure a reasonably low figure for the residual stress.

In boiler repair work where a panel has been cropped from the back of a combustion chamber and renewed by welding, it has been advocated that the line of welding should be wavy or scalloped and not straight, and this method has often been adopted. If care is taken to avoid undue restraint whilst welding, there does not seem to be much advantage in this method. The authors' views on this would be of interest.

With reference to the "restrainer" used in the investigation, it is noted that it was designed to give a restraint (at right angles to the line of weld only) equivalent to that estimated as given in a typical weld of a deck stringer. It is not clear why a definite figure for the degree of restraint was required in the tests as the residual stresses for the various types of gaps welded are stated to be comparative only. The straight line connecting the residual stress and

$$\frac{\text{mean width of weld}}{L}$$

on page 15 would simply have its slope changed for various values of the restraint.

The expression on page 10. for the degree of restraint in terms of cross-sectional areas and length is given in its general form where the areas are a continuous function of length. In the actual design of the "restrainer" the areas are discontinuous, and, therefore, a graphical summation had to be resorted to.

REPLIES.

The excellent attendance at the meeting and the contributions in the discussion reflect considerable interest in the paper. We regret that, in the cause of economy, no more than brief reply is permissible.

The paper, at time of printing, was not complete, some of the conclusions were not fully framed, and these are now given by way of an Appendix, not only to render the record of test complete but also as a reply comprehensive of some of the points raised.

We agree with Mr. Murray that a more extensive series of tests (as was at first contemplated) would have resulted in a nest of curves of which diagram 4 merely shows the general trend. It will be apparent from a study of the Appendix that the real base against which to plot stress is extremely complex. It is true that L and "l," being constants for the series of tests shown, need not have been included, but, in that event, mean width of weld would only have appeared as a function of $\frac{\text{Volume}}{\text{Depth}}$ and the relative importance of L would not have been shown. It is quite likely that an increase in the breadth of the test piece would amend each of the stress values, but we have no reason to suppose that the amendment would not be proportionate throughout that series and, therefore, their comparative values would remain substantially as shown in this series.

In reply to Mr. Ormiston, we indicate in the paper that our use of the term residual stress is comprehensive. He will probably agree that the greater the number of technical terms the more limited is the appeal. We talk a great deal about the influence of the human element in welding and almost deny the interest of many by developing a technique far above ordinary understanding. The paper is not intended for the interest of the few, but there is much in Mr. Ormiston's contribution with which we are in agreement.

Mr. Cocks gives his views broadly under five headings, the first three are interdependent, the fourth is somewhat depressing, and the fifth seems to us to point the way to success.

First he says that residual stress is a bogey, secondly it is potentially dangerous in association with discontinuities, and, thirdly, he says the

influence of residual stress can be discounted if we eliminate the discontinuities. Discontinuities, he proceeds, must be avoided if possible by good design and careful attention, to welding technique. Presumably, therefore, if we cannot avoid discontinuities we are back to the potentially dangerous state, and no doubt will seriously reconsider whether intensive study and research have, indeed, named residual stress as a bogey.

Mr. Cocks will probably agree that good design is a highly controversial subject once we depart from what we know by experience, and even if we could avoid discontinuities in process of building a ship, they can still occur in course of service by way of damage and repair.

Fourthly, he tells us that an all-welded vessel is monolithic, a fracture once initiated will more often than not propagate much further, sometimes with catastrophic results. Actually, and as Mr. Gibbs reminds us, there is no pre-war experience justifying this dire view, and the oldest of all all-welded vessels, the "FULLAGAR," no less monolithic and despite all discontinuities inherent in design and augmented by damage not immediately repaired, remains a veritable advertisement for welding.

Fifthly, we learn what our friends in America are now doing—pre-stressing, pre-heating, peening and heat relief, all with purpose to reduce residual stress which we advocate but by other and less costly method. In this we evolve no new principles but simply give point to those already established—avoid restraint and deposit no more metal than is necessary.

We quite agree with Mr. Gibbs that none but the best of welding should go into a welded structure, but we on repair work do get some surprises, not all defective welding is in the vicinity of fractures, that is one of the disturbing features inclining us to attach due value to residual stress. The form of weld figuring in his concluding inquiry is apparently that shown in weld tests Nos. 7 or 1, but the gap is wider than we found necessary, and so the stress producing effect is higher; all our weld tests were sectioned to check up on penetration, and we advocate closer joints than the standard generally accepted.

Mr. Jaroszynski requests that we enlarge on our practical interpretations. To many the adoption of the "end-to-middle" procedure was no more than a hope that it would be more successful than the generally accepted "middle-to-end" procedure. In all probability when we know more about good design and correct welding technique the difference between these two procedures will figure less. As regards German practice of manning the job so that welding proceeds simultaneously at as many points as possible round the periphery of the section, we would accept that as good practice to ensure uniform distribution of stress, and if the sections were mounted on rollers there would be corresponding reduction in the average value of residual stress. All experience teaches that welding once started should be finished in that heat. Due principally to higher losses at higher amperages there is no straight line relationship between heat input and volume of electrode used, and there is even less relationship between volume of electrode used and the gap as prepared. Further explanation of apparent discrepancies is contained in the Appendix.

Mr. Boyd dwells at length on that which we simply state as "a degree of restraint of 87 per cent was thought to be appropriate for purpose of comparing various forms of butt weld." Surely the term is already sufficiently explained in diagram 3, which takes account of length and —one factor which he omits to note—varying section over that length.

The stress values shown are strictly comparable for the stated conditions of test, but, particular as they are, they do not debar us from drawing certain broad conclusions. Indeed, without test, but only by fair guess, almost anyone would place Weld Test No. 6 at the top, and Weld Test No. 17 at the bottom of the stress scale, and by no process of practical procedure can their relative positions be reversed.

The broad conclusions are these: That the summary gives numerical value to various forms of weld in terms of their stress-producing effect, and it suffices to say that the stress-producing effect of a weld of the form of Weld Test No. 6 is about twice the normal value (taking satisfactory pre-war practice as the standard), and

about ten times what it would be if we adopt the precautions set forth in the Appendix.

In his remarks, Mr. Brooke Smith expresses the doubts and sorrows of one frequently questioned regarding failures and his inability to offer simple explanation. He ascribes to us, through misplacement of italics, statements which are extracts from the official findings so far published but not yet complete. We simply present a statement of our experience and test for discussion, hopeful that the result may contribute to finding a satisfactory solution.

Mr. Champness states and we accept, that the test results cannot be other than generally applied, but as explained in the reply to Mr. Boyd's remarks, that is no unimportant gain. We agree that the larger rods and higher amperages require more careful handling, we do not agree that they fail to provide full penetration when properly used.

To Mr. Reid's inquiry we would confirm that the specimens and all the apparatus other than the pins were of ordinary ship quality mild steel. The ends of the test welds were not ground flush, carbon blocks were placed at each end of the gap and so retained the weld metal to a uniform dimension of length.

We are quite in agreement with Mr. Gibbeson's remarks, the import of which is that much as we are agreed on the need for good welding it is not likely to be good if welding conditions are not favourable.

Mr. Naisby is quite correct, but the error in using L instead of L — d accounts for an error of less than one in one thousand.

Mr. Campbell seeks our opinion of the scalloped edge. Theoretically it may possess certain advantage but this is likely to be off-set by cost of preparation, constant change of angle in welding and greater volume of weld metal.

Eighty-seven per cent degree of restraint is only a particular value simply determined; it suffices that we consider the degree of restraint frequently experienced to be of that order; we had to determine some value in order to design the apparatus and to adhere to that value throughout the series of tests if we were to compare various forms of weld in terms of their stress-producing effect.

APPENDIX

It can be said with confidence that any reduction in the average value of residual stress will mean fewer structural failures, and the Summary of Test Results arranged in order of their stress-producing effect, comparative values, affords the necessary guidance.

Outstanding merit obviously attaches to the square-face, no-gap, two-run form of weld with negligible average value of residual stress despite high restraint and the use of large electrodes and heavy welding current, and this form of weld and others derived from it are, therefore, eminently suitable for large prefabricated assemblies, the "in situ" welds joining them and repair work, provided the following dependent conditions are carefully and fully satisfied:—

(*a*) Initial close fit in association with deep root face.

(*b*) The use of deep penetration electrodes.

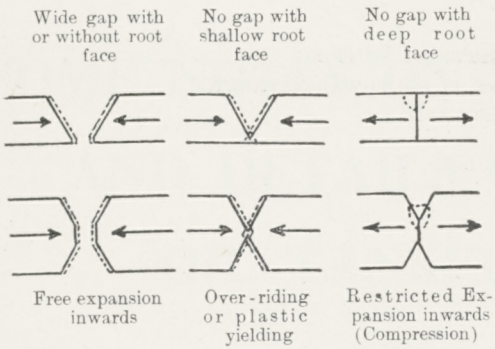
(*c*) A substantial portion of the root face remains unfused by the first run.

The merits of conditions (*a*) and (*b*) will be apparent in that they combine to satisfy the primary need—the minimum deposit of weld metal consistent with assuring a good weld; the merit of condition (*c*) is less apparent but equally important and its absence due to the first run fusing the whole of the root face was identified in course of these tests as chiefly accounting for certain inconsistencies in the results, particular cases being the inordinately high value both for Weld Test No. 4 and the preliminary tests on the square-face, no-gap, single run weld on thinner material, indeed, results in both cases were more consistent with gap than with no gap.

In these tests on specimens with their outer ends relatively fixed, it became apparent that the immediate and, for brief period, continuing effect of welding heat for all runs, but more so for the first run, is to cause appreciable expansion inwards, i.e., closing the gap when gap is provided and compressing the abutting faces

when there is no gap but adequate root face. This closing of the gap due to welding heat and the inability of the parent parts to contract by similar amount on cooling, due to their then being linked together with a layer of contracting weld metal, is a principal cause for stress; on the other hand, compression of the abutting faces due to welding heat, and in all but a small amount of plastic yielding, is dissipated by subsequent contraction on cooling—a difference effect that alleviates stress and was markedly present in the square-face, no-gap, two run form of weld when the first run leaves fully half of the root face unfused, thereby assuring an approximate balance of compression and tension in the completed weld, i.e., negligible average value of residual stress.

Expansion inwards due to welding heat of the first run :—


Wide gap with or without root face
No gap with shallow root face
No gap with deep root face
Free expansion inwards
Over-riding or plastic yielding
Restricted Expansion inwards (Compression)

Expansion inwards is less marked for the second and subsequent runs due to the restraining influence of the first and subsequent runs; and the predominating influence for stress is then the width of fusion zone, i.e., width of gap plus lateral penetration.

Since the beneficial effect of correct "in situ" heat treatment (raising the temperature up to 600 degrees C. and prolonging the cooling as much as possible) is not evident in these tests in terms of stress, it follows that the locally high values within the weld have been reduced at the expense of raising the low values, i.e., without influencing the average value of stress and, if the latter is negligible without heat treatment, then the effect of heat treating the weld is to reduce all stresses within the weld for width and depth to negligible amount. Heat treatment of the weld may have particular appeal in certain cases, it requires no special appliances other than substituting a carbon electrode for the normal welding electrode, adjustment of current and check test by thermo couple to ensure that 600 degrees C. is reached but not exceeded, though this method is open to the objection that there may be an adverse pick up of carbon. The meaning attached to the higher average value of residual stress by raising the temperature to 800 degrees C. (see Weld Test No. 13) is that a greater width was raised to that temperature than had obtained during the welding operations, resulting in additional plastic yielding under compression—local thickening rather than buckling —and, therefore, higher average value of stress ensued.

These tests did not extend to an investigation of stress in the dimension of length of weld, but experience supports the view that planned wandering and step-back methods lead to better distribution of stress and lower average values than is afforded by a continuous run. Heat treatment of the weld as above would reduce all locally high values of stress in length and, in the absence of heat treatment, chipping the surfaces of the weld down to the flush would remove the most highly stressed part of the weld without impairing the efficiency of the joint.

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SOME NOTES ON THE CONSTRUCTION AND DETAILS OF THE WELDED OIL TANKER "HELICINA."

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SOME NOTES ON THE CONSTRUCTION AND DETAILS OF THE WELDED OIL TANKER "HELICINA."

THIS paper is not written with the idea of evoking too much discussion or to establish any hard and fast methods of construction which are not subject to modification, but with the intention of it being a guide to colleagues who have not had the opportunity of being associated with the all-electric welded construction of large vessels. An endeavour has been made to set out in some detail the methods employed in the building of a large oil tanker.

It will be recognised that the builders can be considered as pioneers in the gradual change over from riveting to welding which has taken, and is taking, place in the shipbuilding industry, and this vessel is the outcome of many years of intensive effort to establish a method which, up to the time of writing this paper, appears satisfactory. A sister vessel taken over by the Admiralty with Lloyd's Register highest class, in May, 1945, is reported to be operating to the satisfaction of all concerned.

I feel some remarks regarding the part designers and drawing office staff can take in the preparation of drawings and welding specification will not be amiss.

My experience leads me to think that to become successful shipbuilders, building all-welded vessels, drawing office staffs should undergo training in this branch of shipbuilding. In fact, I think it is time it was included in the Naval architecture course of our Universities and Technical Colleges, including also a course of practical welding, so that the students may better understand the actual technique of welding and so avoid designing joints which are inaccessible for welding and uneconomical to produce. It should also be impressed upon drawing office personnel that to ensure the best results from welding in ship construction the number of parts should be kept to a minimum by the use of large plates and available rolled sections.

A typical part specification which should be issued to the Yard is shown below.

TYPICAL WELDING SPECIFICATION.

ITEM.	Position	No. of Runs.	Gauge.	Amps.	Deposit.	THROAT THICKNESS.
·50 in Butt	D.O.	1	6	200	12 in	
,,	D.O.	2	0	300	12½in.	
,,	O.H.	1	8	140	13 in.	Sealing run
Bulkheads to Shell	V.	2 E.S.	8	140	10 in.	·24 in.

TYPE OF ELECTRODE :

The vessel is the largest of its type, I understand, to be attempted in this country, the principal dimensions being :—

Length O.A.	583 ft. 5 ins.
Length B.P.	550 ft. 0 ins.
Breadth	70 ft. 0 ins.
Depth	40 ft. 6 ins.
Displacement	25,040 tons.
Deadweight	18,100 tons.
Gross Tonnage	12,167 tons.

The propelling machinery is turbo-electric, but that is another story, suffice to say the attained speed is 17 knots.

It is not my intention to offer any criticism regarding the cost and time to build.

I have included a number of drawings which will be referred to as the paper proceeds, no photographs were taken during construction, and I regret there are no slides.

The main scantlings and general layout are as indicated in Figs. 1 and 2 respectively.

I now come to the methods employed in the building, and commence with the bottom shell plating. This was designed in accordance with Fig. 3. The flat keel is laid complete barring those plates at the extreme ends of the vessel, the butts are welded before any other work is started, welding commencing at amidships and working to the ends. On completion supports are erected and the bottom plating is laid and faired and welded, the sequence being as indicated, commencing always at amidships and working to the ends of the vessel, the preparation of joints being as shown in Fig. 4. I think I should mention that in the first vessel the preparation of the joints was as shown in Fig. 5, and when the whole flat of bottom was complete, it was like a switchback, but faired itself out when the bottom longitudinals and longitudinal bulkheads were erected and welded down to the plating. However, the initial unfairness gave all concerned considerable worry, and it was decided after experiment to adopt the preparation as shown in Fig. 4 in this vessel. The welding procedure in the first vessel was as follows :—

Top down hand welding of seams and butts completed, and the overhead sealing runs carried out as operators were available. In the "Helicina" the welding procedure was altered as follows :—

Two top down hand runs of seams and butts completed and the two overhead sealing runs carried out and completed concurrently with the further down hand runs, the overhead operators following on in reasonably close succession. The result was satisfactory with no appreciable unfairness. Concurrently with this work various parts of the structure such as longitudinal and transverse bulkhead stringers, bottom and top transverses for wing and centre tanks, centre girders for bottom and deck, the large centre line webs (Fig. 13) for transverse bulkheads, bottom longitudinals are being built complete at the gantries on the ground in order that the sequence of erection can proceed without delay.

LONGITUDINAL BULKHEADS.

Fig. 6. As fabricating space in the yard is somewhat restricted, after the flat of bottom is completed, rails are laid on this and the longitudinal bulkheads constructed in panels, panel A consisting of one plate and two stiffeners, panel B of three plates and stiffeners. This can be varied of course in order to suit the length of tanks and width of plates which can be suitably handled. The stiffeners, stiffener brackets and stringers are all welded on the gantry in the down hand position in the following order :—

(1) Butts of plates—welding commencing at centre of butt.

(2) Stiffeners—welding from one end straight through.

(3) Stiffener Brackets.

(4) Stringers—welding commencing at centre.

The various panels are so placed on the flat of bottom that each section can be erected in its correct position. Starting from aft, panel A is erected first, followed by panel B, and then panel C and this procedure is carried on throughout. The overlap joints are left for fairing and are not welded until the various panels are correctly placed.

TRANSVERSE BULKHEADS.

Fig. 7. These are dealt with in a similar manner to the longitudinal bulkheads. The butt preparation of the longitudinal and transverse bulkheads is as shown in Fig. 8 and the preparation for the sealing run on the reverse side has to be gouged out and the welding carried out in the vertical and horizontal position when the bulkheads are erected.

DOUBLE BOTTOM UNDER ENGINES.

FIG. 9. This tank differs somewhat in design from those with which we are most accustomed to deal on account of the turbo-electric machinery, and I have endeavoured, in the drawing, to show this as clearly as possible. If the structure is taken panel by panel, I trust that the appearance of the finished job may be intelligible. It is designed in sections of suitable size and weight to suit the lifting capacity of the Yard and is built on the ground in a position alongside the building berth for an easy lift to its correct position in the ship. It is fabricated in the following manner :—

PANEL A.

(1) The tank top plates are prepared, placed on the welding gantry, and welded together, all welding commencing from the centre of the seams.

(2) The centre girder is then positioned and welded to the tank top, welding commencing at the centre.

(3) Floors to centre girder, welding commencing at the tank top and continuing upwards.

(4) Floors to tank top welding commencing at centre girder.

(5) Intercostal girders to tank top, welding commencing at centre of Intercostal.

(6) Intercostal girders to floors, welding commencing at tank top and continuing upwards.

The remaining panels are prepared in a similar manner and as completed each panel is turned over into its correct position at the building berth.

To complete the tank top the whole is welded together in the following order :—

(1) Panels A to B to C and D.

(2) Panels C to D to E and F.

(3) Panels E to F to G.

(4) Centre girder butts welding commencing at bottom.

(5) Intercostal girders at joints of floors, welding commencing at bottom.

(6) Fillets of Panels E and F to Panels H and I.

(7) Fillet of Panel G to Panels H and I.

(8) Panel H and I to Panel J.

(9) Fillet of Panel G to Panel J.

(10) Centre girder to shell commencing at centre.

(11) Floors to shell welding commencing at centre girder.

(12) Intercostal girders to shell welding commencing at centre of Panels.

UPPER DECK.

FIG. 10. The plating over the whole of this deck is arranged as shown in Fig. 10, and is designed substantially as a riveted job regarding butts and seams. No special method of fabricating large sections is employed, each individual plate being laid and welded plate by plate. The centre strake is laid fore and aft to commence with and the butts welded, starting at the centre of the vessel and working to the ends in a similar manner to the flat keel.

Before the upper deck plating is laid, all the deck transverses, longitudinal deck beams, and upper deck centre girder are erected, and as the seams and butts of the plates are welded complete, the attachments of the foregoing plus transverse bulkheads are welded to each individual plate, working from centre of vessel outwards and fore and aft respectively.

The connection of the upper deck stringer plate to the sheerstrake is a joint about which there has been a good deal of controversy. I am informed that some all-welded ships have a riveted stringer angle for this connection. The builders have, however, a great deal of faith in welding and this joint is welded. The "NEVERITA" and "OLNA", both similar ships to the one under review, have this type of joint and have, up to the time of writing, proved satisfactory. A great deal of careful consideration is given to this joint and it is the last one to be welded, as far as the main structure is concerned. The sheerstrake butts and lower seam are completed, but the riveting through the frames

is left until the joint is complete. The stringer plate is laid before the sheerstrake is erected, and is left with a certain amount of scrap in the width, and is carefully lined off to the shape required, then flame cut square, then the vee preparation is flame cut, and sheerstrake erected and completed except riveting. The welding of the joint is as shown in Fig. 11. The height of the sheerstrake above the upper deck is three inches moulded. The tops of all welded butts of the sheerstrake and the joints of all side plating at the breaks of poop, bridge and forecastle to the sheerstrake top are filled or buffed smooth to remove all possible notches which might create fractures. Care is also taken to avoid having any fittings, etc., welded to the top edge of the sheerstrake.

SHELL PLATING.

Fig. 12. The plating above flat of bottom is erected plate by plate with shift of butts corresponding substantially to a riveted shell. The welding sequence is as indicated, and commences amidships, working outwards to the ends. Butts must be welded first and the welding commences at the bottom of the plate and is worked up over. I feel I should mention here that the holes in the frames are punched a size smaller than is finally required, and slightly slack bolts are used to hang the plates; this method demonstrates that very little help is needed, when welding the seams, from the appliances generally used to keep the plating fair as the welding proceeds.

At the ends of the vessel care was taken in designing the joints to ensure that the welding can be done in the down hand position as far as possible, leaving the sealing run to be done overhead.

ERECTION SEQUENCE OF MAIN STRUCTURE.

(1) Keel plate.
(2) Flat of bottom shell plating.
(3) Longitudinal bulkheads.
(4) Vertical centre keelson.
(5) Transverse bulkheads in centre tanks.
(6) Bottom longitudinals in centre tanks.
(7) Bottom transverses in centre tanks.
(8) Transverse bulkheads in wing tanks.
(9) Bottom longitudinals in wing tanks.
(10) Bottom transverses in wing tanks.
(11) Side frames and knees.
(12) Upper deck centre girder.
(13) Upper deck longitudinals.
(14) Deck transverses in centre tanks.
(15) Struts in wing tanks.
(16) Deck transverses in wing tanks.
(17) Stringers to shell.
(18) Upper deck plating.
(19) Side shell plating.

Joints. The preparation of the plates edges, etc., depends on the type of joint, thickness of plates and their position in the ship. It is very essential that care should be taken in the shops to ensure that the planed edge preparation is correct and that the individual parts fit into the various positions at the berth.

While flame cutting to overcome too close fitting or unfairness has at times to be resorted to, I would stress the point that this should be avoided as much as possible.

I feel that one of the first essentials of good welding is to start right and so give the operators a fair chance.

I have only endeavoured to describe the erection sequence of the main components, without details relating to such parts as deckhouses, engine and boiler casings and general deck superstructures, as I am sure most of you will be familiar with the methods employed in the construction and assembly of these parts.

The methods which are adopted and the allowances made to counteract distortion, for keeping the work in position during welding, etc., are so varied that I feel they could form the basis of a paper on its own. It is not proposed to deal with these now, but I do not wish you to conclude they are of no importance, as the erection sequence drawings would not be a great deal of use if the correct setting-up of the joints, the choice of welders and the supervision of the welding were not duly considered in a similar manner.

Experience shows that there is considerable scope for intelligent craftsmen to invent their own means of overcoming difficulties which may occur. Suffice for me to say that the limited guidance given in the Memorandum issued by the Admiralty: "The Application of Electric Arc Welding to Ship Construction. M.2," copies of which I imagine you all have, does form a sound basis for this work.

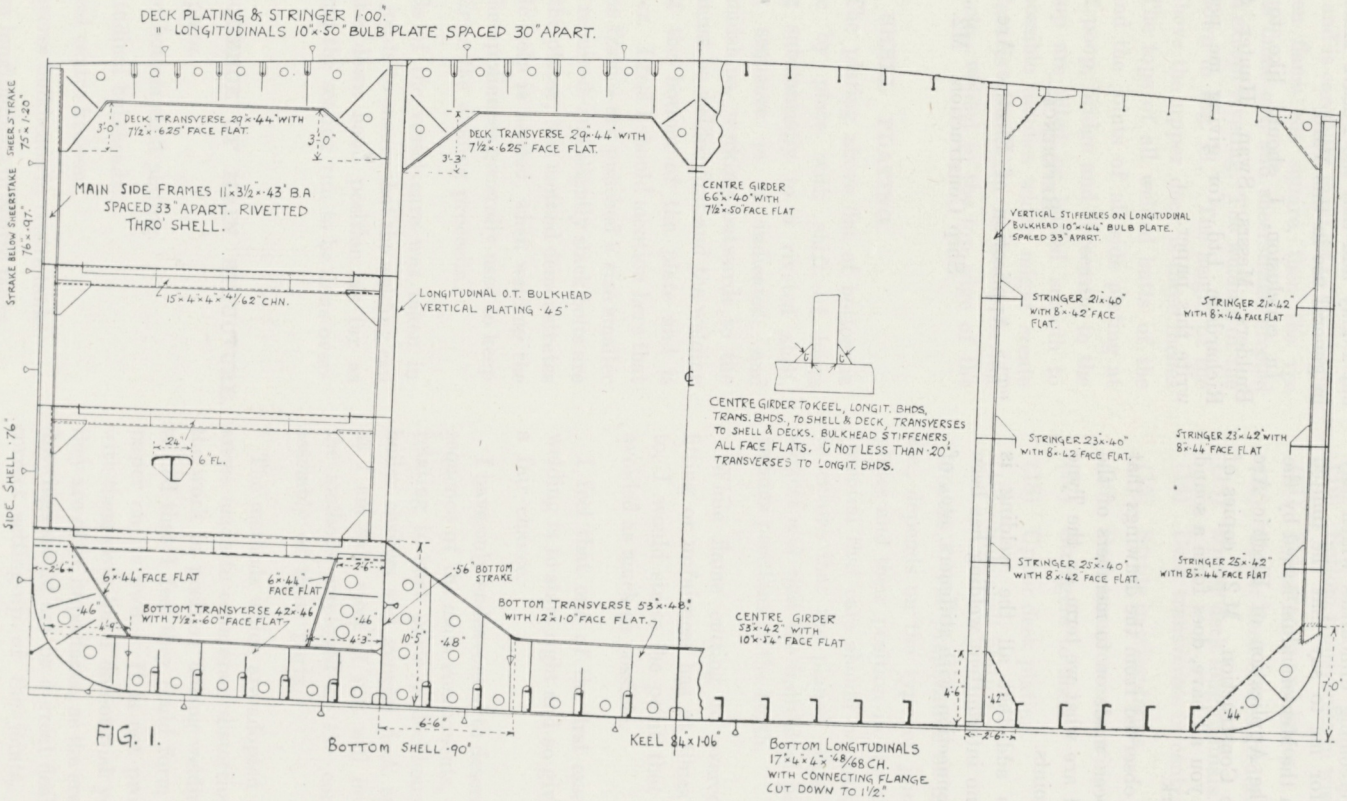
You may have observed from the drawings that no welds have been made on to members of the structure, but all are what we term on the Tyne free butts and joints.

I should also add that all the welding is continuous and no intermittent welding has been used except in connection with stiffeners, etc., of minor bulkheads, casings, etc. All welding is done manually, no machines having been employed, but I may add that the Fusarc Machine is now in general use in this Yard.

In conclusion, I should like to thank the Builders, Messrs. Swan, Hunter & Wigham Richardson, Ltd., for giving me permission to write this paper.

REFERENCE—

"The Application of Electric Arc Welding to Ship Construction. M2."


DECK PLATING & STRINGER 1·00"
" LONGITUDINALS 10"×·50" BULB PLATE SPACED 30" APART.
SHEER STRAKE 75"×1·20"
STRAKE BELOW SHEERSTRAKE 76"×·97"
SIDE SHELL ·76"
DECK TRANSVERSE 29"×44" WITH 7½"×·625" FACE FLAT.
3'·0"
3'·0"
DECK TRANSVERSE 29"×44" WITH 7½"×·625" FACE FLAT.
3'·3"
MAIN SIDE FRAMES 11"×3½"×·43" B.A SPACED 33" APART. RIVETTED THRO' SHELL.
15"×4"×4"×½"/62 CHN.
LONGITUDINAL O.T. BULKHEAD VERTICAL PLATING ·45"
24"
6" FL.
CENTRE GIRDER 66"×·40" WITH 7½"×·50" FACE FLAT
CENTRE GIRDER TO KEEL, LONGIT. BHDS, TRANS. BHDS., TO SHELL & DECK, TRANSVERSES TO SHELL & DECKS, BULKHEAD STIFFENERS, ALL FACE FLATS. G NOT LESS THAN ·20" TRANSVERSES TO LONGIT. BHDS.
VERTICAL STIFFENERS ON LONGITUDINAL BULKHEAD 10"×44" BULB PLATE. SPACED 33" APART.
STRINGER 21"×·40" WITH 8"×·42" FACE FLAT.
STRINGER 21"×·42" WITH 8"×·44 FACE FLAT
STRINGER 23"×·40" WITH 8"×·42 FACE FLAT.
STRINGER 23"×·42" WITH 8"×·44 FACE FLAT
STRINGER 25"×·40" WITH 8"×·42 FACE FLAT.
STRINGER 25"×·42" WITH 8"×·44 FACE FLAT
2'·6"
6"×·44" FACE FLAT
6"×·44" FACE FLAT
2'·6"
·56" BOTTOM STRAKE
·46"
·44"
BOTTOM TRANSVERSE 42"×·46" WITH 7½"×·60" FACE FLAT.
·46"
6'·3"
10'·5"
·48"
BOTTOM TRANSVERSE 53"×·48" WITH 12"×1·0" FACE FLAT.
CENTRE GIRDER 53"×·42" WITH 10"×·54" FACE FLAT
4'·6"
·42"
·44"
7'·0"
2'·6"
6'·6"
FIG. 1.
BOTTOM SHELL ·90"
KEEL 84"×1·06"
BOTTOM LONGITUDINALS 17"×4"×4"×·48/68 CH. WITH CONNECTING FLANGE CUT DOWN TO 1½"

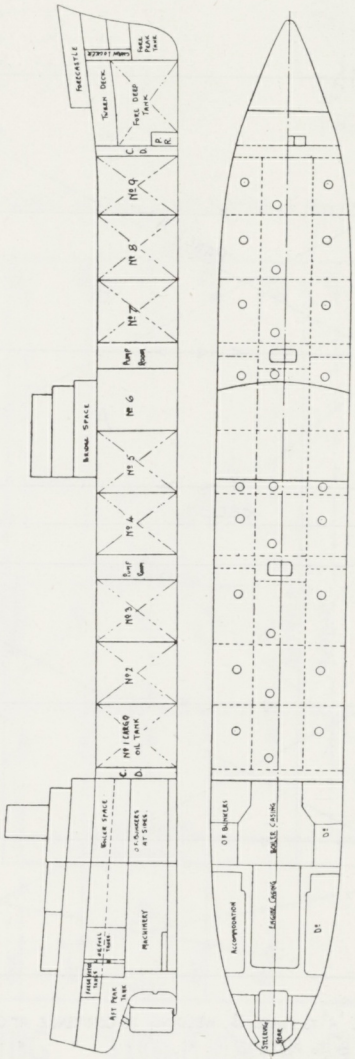
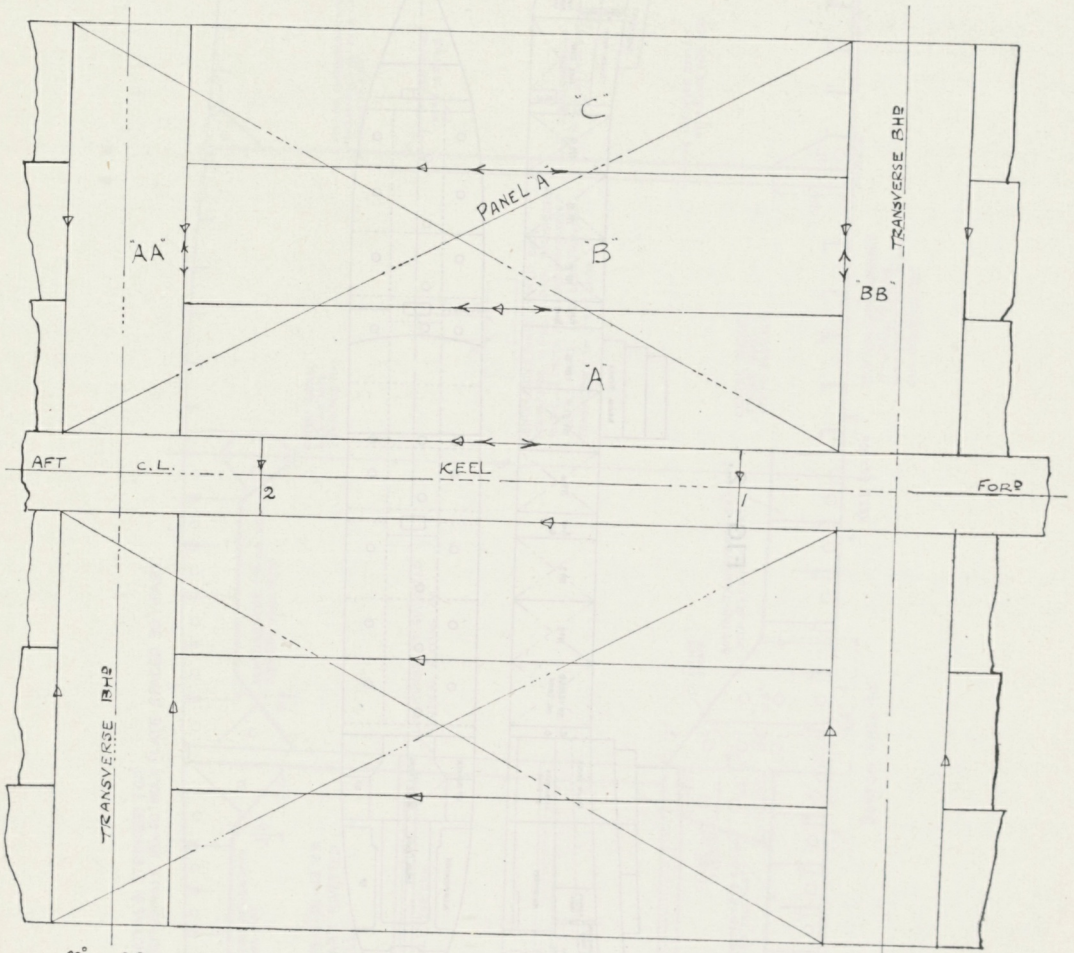

FORECASTLE
SEAMEN DECK
FUEL DEEP TANK
No 8
No 7
No 6
No 5
No 4
No 3
No 2
No 1 CARGO OIL TANK
BOILER SPACE
ENGINE SPACE
MACHINERY
AFT PEAK TANK
ACCOMMODATION
BOILER CASING
STEERING GEAR

FIG. 2.

SEQUENCE OF WELDING BOTTOM SHELL.

FIG. 3.



1. WELD PLATE "A" TO PLATE "B". WELDING TO COMMENCE AT CENTRE.
2. WELD PLATE "B" TO PLATE "C"
3. WELD PLATE "AA" TO PLATE "ABC"
4. WELD PLATE "BB" TO PLATE "ABC"
5. WELD COMPLETE PANEL TO KEEL. WELDING TO COMMENCE AT CENTRE.

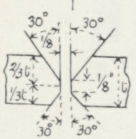


FIG. 5.

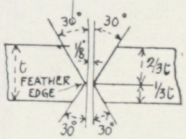


FIG. 4.

1. WELD PLATE 1 TO PLATE 2 - PANELS 'A' & 'C' IN DIRECTION OF ARROWS.
2. " STIFFENERS TO PANELS 'A' & 'C' " " " " "
3 " PLATE 1 TO PLATE 2 - PANEL 'B' " " " "
4 " " 3 " PLATES 1 & 2 " " " " "
5. " " 4 " " 1, 2 & 3 " " " " "
6. " STIFFENERS TO PANEL 'B' " " " "
7. " STRINGERS " " " " " "
8. " BRKTS. TO STIFFENERS
9. ERECT PANEL 'A' WELD TO SHELL " " " "
10 " " " 'B' " " " " " "
11. " " " 'C' " " " " " "
12. WELD OVERLAP BUTTS OF PANELS 'A', 'B' & 'C' COMMENCE AT BOTTOM & PROCEED IN DIRECTION OF ARROWS.

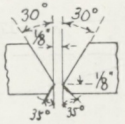


FIG. 8

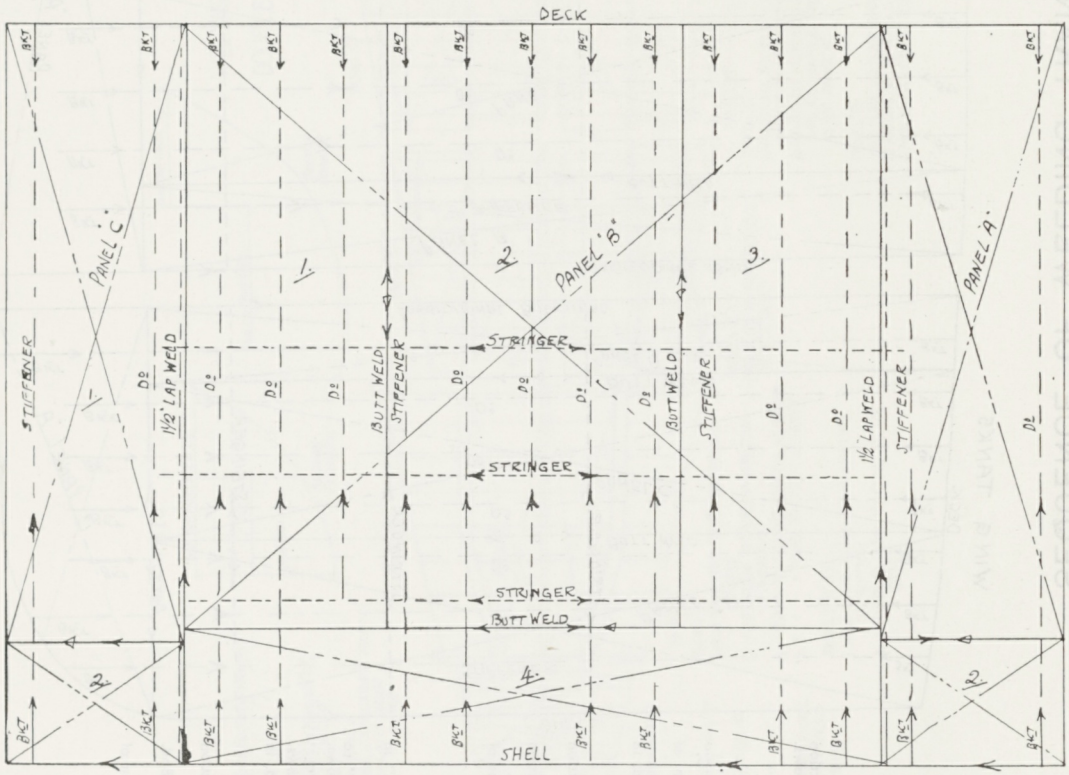
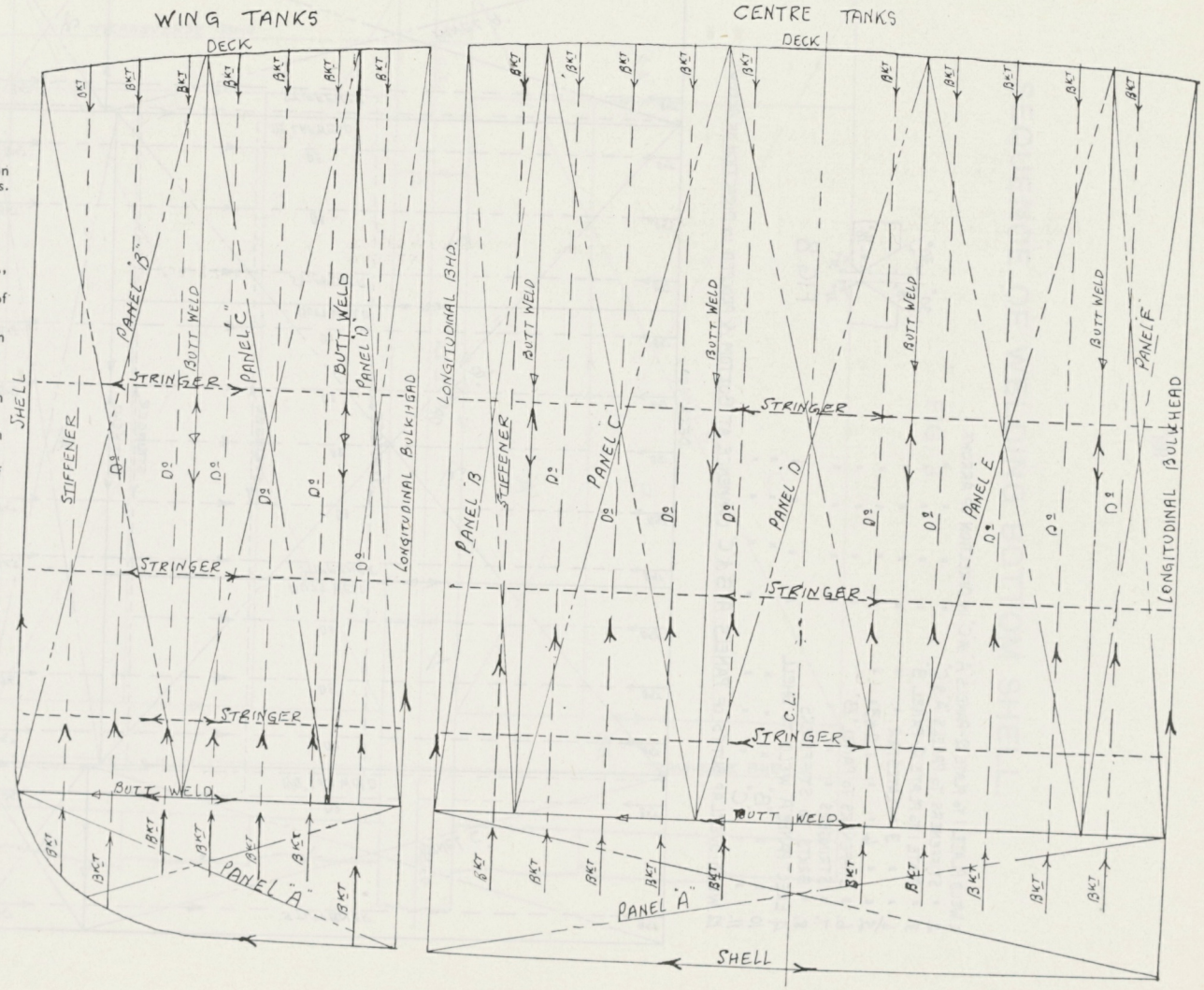


FIG. 6. SEQUENCE OF WELDING. LONGITUDINAL BULKHEAD PANELS.

FIG. 7.

SEQUENCE OF WELDING TRANSVERSE BULKHEADS.



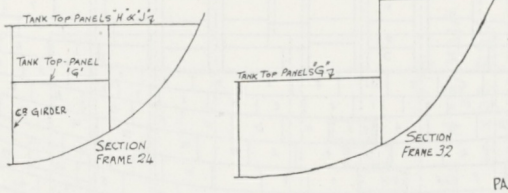
CENTRE TANKS.

1. Weld Butt of Panel "B" to "C" in direction of arrows.
2. " " "C" " "D" " "
3. " " "D" " "E" " "
4. " " "E" " "F" " "
5. " " "A" " Panels "B," "C," "D," "E," & "F" in direction of arrows.
6. Weld Stiffeners to complete Bhd. in direction of arrows.
7. Weld Brackets to Stiffeners.
8. Weld Stringers to Bhd. in direction of arrows.
9. Erect Bhd. & Weld to Shell in direction of arrows.
10. Weld to Longit. Bhd. in direction of arrows.

WING TANKS.

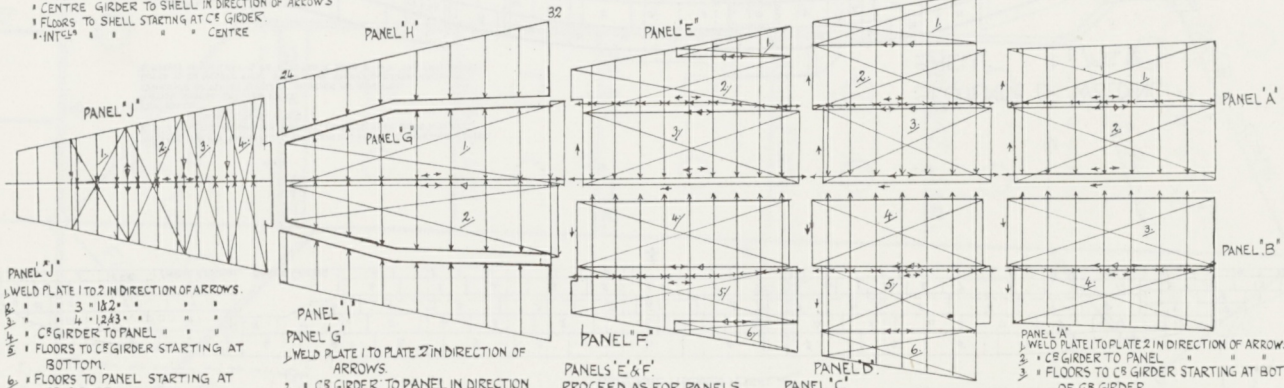
1. Weld Butt of Panel "B" to "C" in direction of arrows.
2. Weld Butt of Panel "B" & "C" to Panel "D" in direction of arrows.
3. Weld Butt of Panel "A" to "B," "C" & "D" in direction of arrows.
4. Weld Stiffeners to complete Bhd. in direction of arrows.
5. Weld Brackets to Stiffeners.
6. Weld Stringers to Bhd. in direction of arrows.
7. Erect Bhd. & Weld to Longit. Bhd. in direction of arrows.
8. Weld Bhd. to Shell in direction of arrows.

WELDING SEQUENCE.
DOUBLE BOTTOM IN ENGINE ROOM. FIG. 9.



TO COMPLETE.

WELD PANEL 'A' TO 'B' TO 'C' & 'D' IN DIRECTION OF ARROWS.
" " 'C' " 'D' " 'E' 'F' " " " "
" " 'E' " 'F' " 'G' " " " "
" C.L. GIRDER BUTTS.
" INT.L.S AT JOINTS OF FLOORS.
" FILLET OF PANELS 'E' & 'F' TO PANELS 'H' & 'I'.
" " " " " 'H' & 'I' TO PANEL 'G'
" PANEL 'H' & 'I' TO PANEL 'J'.
" FILLET OF PANEL 'G' TO PANEL 'J'.
" CENTRE GIRDER TO SHELL IN DIRECTION OF ARROWS
" FLOORS TO SHELL STARTING AT C.L. GIRDER.
" INT.L.S " " " " CENTRE



PANEL 'J'
1. WELD PLATE 1 TO 2 IN DIRECTION OF ARROWS.
2. " " 3 " 1 & 2 " " " "
3. " " 4 " 1 & 3 " " " "
4. " C.L. GIRDER TO PANEL " " "
5. " FLOORS TO C.L. GIRDER STARTING AT BOTTOM.
6. " FLOORS TO PANEL STARTING AT C.L. GIRDER.

NOTE:- ON COMPLETION EACH PANEL IS TURNED OVER & PLACED IN POSITION AT SHIP

PANEL 'G'
1. WELD PLATE 1 TO PLATE 2 IN DIRECTION OF ARROWS.
2. " C.L. GIRDER TO PANEL IN DIRECTION OF ARROWS
3. " FLOORS TO C.L. GIRDER STARTING AT BOTTOM.
4. " " " PANEL STARTING AT C.L. GIRDER.

PANELS 'H' & 'I'.
1. WELD FLOORS TO SIDE GIRDER STARTING AT BOTTOM.
2. " FLOORS TO PANEL STARTING AT SIDE GIRDER.

PANELS 'E' & 'F'.
PROCEED AS FOR PANELS 'A', 'B', 'C', & 'D'.

PANEL 'C'
1. WELD PLATE 3 TO PLATE 2 IN DIRECTION OF ARROWS.
2. WELD PLATE 1 TO PLATES 2 & 3 IN SIMILAR MANNER. THEN PROCEED AS FOR PANEL 'A'.

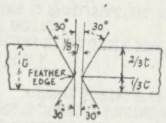
PANEL 'D'
WELD PLATE 4 TO PLATE 5 IN DIRECTION OF ARROWS. WELD PLATE 6 TO PLATES 4 & 5. & PROCEED IN A SIMILAR MANNER.

PANEL 'A'
1. WELD PLATE 1 TO PLATE 2 IN DIRECTION OF ARROWS.
2. " C.L. GIRDER TO PANEL " " "
3. " FLOORS TO C.L. GIRDER STARTING AT BOTTOM OF C.L. GIRDER.
4. " FLOORS TO PANEL " " C.L. GIRDER.
5. " INT.L. GIRDER TO PANEL IN DIRECTION OF ARROWS
6. " " " " FLOORS STARTING AT BOTTOM.

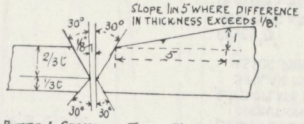
PANEL "B".
WELD PLATE 3 TO PLATE 4 IN DIRECTION OF ARROWS & PROCEED AS FOR PANEL 'A' EXCEPT ITEM 2.

SEQUENCE OF WELDING UPPER DECK FIG. 10

1. ERECT CENTRE STRAKE & WELD BUTTS COMMENCING AMIDSHIPS.
2. ERECT 'A' STRAKE & WELD BUTTS THEN WELD TO CENTRE STRAKE.
3. ERECT 'B', 'C' & 'D' STRAKES & WELD IN SIMILAR MANNER.

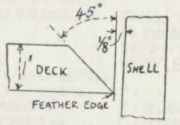


DECK BUTTS & SEAMS.



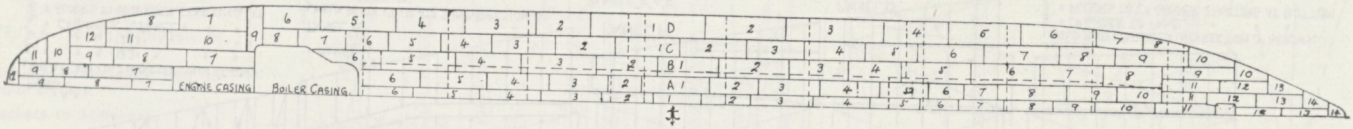
BUTTS & SEAMS AT THICK PLATING GENERAL THROUGH VESSEL.

FIG. 11



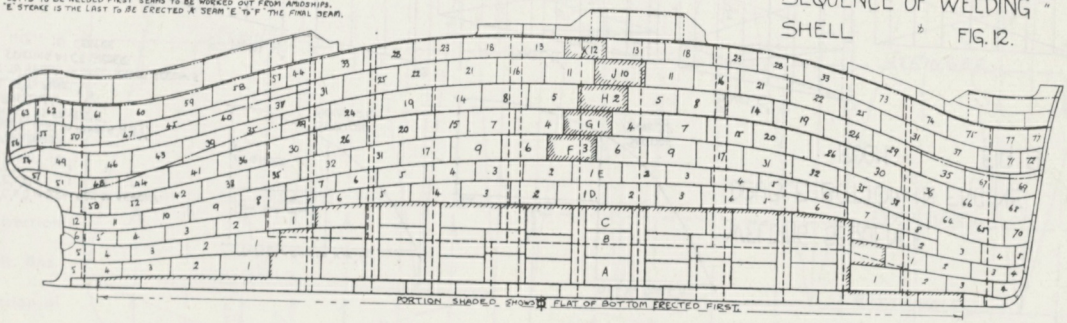
DECK STRINGER TO SHELL.

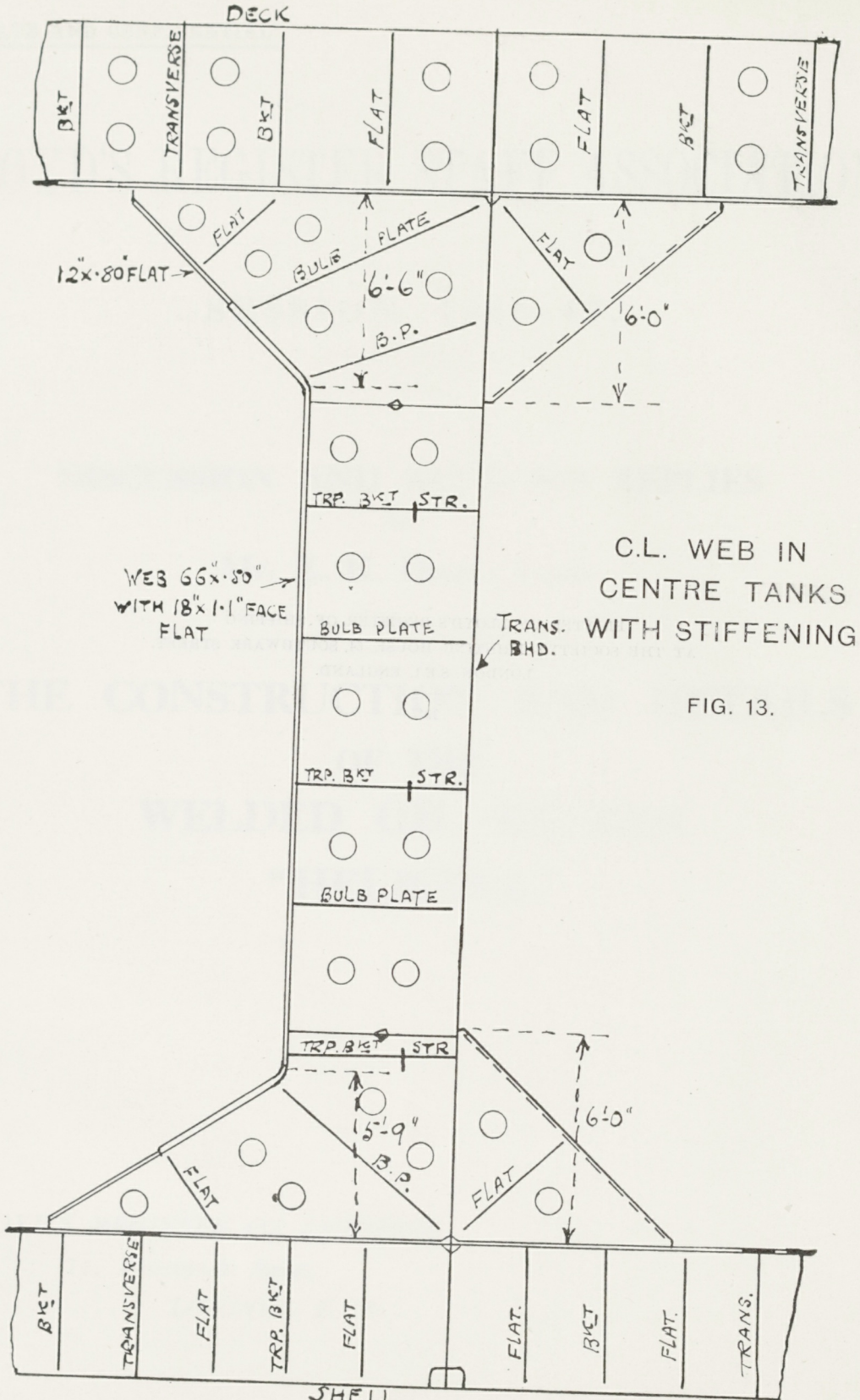
2 RUNS 8 GAUGE ELECTRODES } DOWN HAND.
7 " 4 " " "
2 " 8 " " " } SEALING RUNS.



'D' STRAKE ERECTED, BUTTS WELDED THEN SEAM TO 'C' STRAKE COMMENCING AT CENTRE.
'A', B, & 'C' AFT & FOREWARD ERECTED, BUTTS WELDED, THEN SEAM 'A' TO KEEL,
'B' TO 'A', 'C' TO 'B', 'D' TO 'C'.
SIDE SHELL.
PORTION SHADED ERECTED FIRST.
REMAINDER OF PLATES TO FOLLOW IN ORDER AS INDICATED.
BUTTS TO BE WELDED FIRST. SEAMS TO BE WORKED OUT FROM AMIDSHIPS.
'E' STRAKE IS THE LAST TO BE ERECTED. 'A' SEAM 'E' TO 'F' THE FINAL SEAM.

SEQUENCE OF WELDING SHELL FIG. 12.





C.L. WEB IN CENTRE TANKS WITH STIFFENING

FIG. 13.

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SESSION 1946-47.

DISCUSSION AND AUTHOR'S REPLIES
on
Mr. E. H. Dean's Paper

THE CONSTRUCTION AND DETAILS OF THE WELDED OIL TANKER "HELICINA."

LLOYD'S REGISTER OF SHIPPING,
71, Fenchurch Street,
LONDON, E.C.3.

The Author of this paper retains the right of subsequent publication, subject to the sanction of the Committee of Lloyd's Register. Any opinions expressed and statements made in this paper and in the subsequent discussion are those of the individuals.

DISCUSSION ON MR. E. H. DEAN'S PAPER ON "THE CONSTRUCTION AND DETAILS OF THE WELDED OIL TANKER 'HELICINA'."

MR. R. B. SHEPHEARD.

I should like to ask Mr. Dean one question. From his description, given on page 3, of the sequence of welding adopted for the double bottom engine room units, it appears that the intercostal girders have been connected to the floors as the last stage in the welding operations. In the case of the large double bottom units prefabricated in California for the "Ocean" ships, a rather similar sequence was adopted in the first instance, the welding of the floors and girders to the tank top plating in the inverted position being completed before connections were made between the intercostal girders and the floors. The cumulative contraction of these latter fillet welds was found, when the first long double bottom section was turned over, to have resulted in quite a considerable hog over the length of the unit. The sequence was subsequently changed to complete the welding together of the box structure of the floors and girders before these were connected to the tank top plating, with satisfactory results.

Will Mr. Dean tell us whether the sequence described in the paper has been found to be free from similar distortion effects?

MR. J. S. ORMISTON.

The Association is particularly fortunate in having such a paper as this read before it. This is a factual paper and full of interesting information for all those who may be involved in the supervision of welded ships, and I think that the Association's thanks are due not only to the author but to the builders for giving permission to impart all the information given in the paper.

With regard to the double vee welds shown, I would like to ask the author whether he considers the unsymmetrical double vee preferable to a symmetrical double vee? Doubtless the latter arrangement involves more overhead welding, but makes for the minimum amount of distortion to be provided against. Might I ask if the author would kindly, in replying to the discussion show us a sectional view of each run of the double vee weld? This is always interesting and instructive.

The author's remarks on page 3 regarding the connection of the upper deck stringer plate to the sheerstrake are very interesting, and I am wondering whether it is the best thing to make this joint the last one to be welded.

No doubt a riveted connection between the stringer and the sheerstrake plates makes for safety, but there is a considerable successful experience in dry cargo ships of about 400 feet length with a welded connection. It might be an advantage to make a seam in the deck near the centre line of the ship, a lap joint. This would give greater freedom while the welding of the upper deck stringer to the sheerstrake was being carried out and the lap joint could be welded afterwards, while in way of large cargo hatchways there is greater freedom for movement.

On page 4, under the heading of "Joints," the author speaks critically of flame cutting, but I thought that flame cutting for the preparation of veed joints was quite a common practice, and, so far as my own experience goes, I do not know of any trouble having arisen.

Further, I should like to ask the author whether there was any shortening of ship or lifting up of the ends of ship arising from welding of the structure.

MR. F. C. COCKS.

The author does well to underline the importance of close co-operation between the Drawing Office and the Shipyard in arranging

details and welding procedure. Welding is still a comparatively new method of construction, and as such is capable of radical amendment and redesigning before the fullest advantage can be taken of it. The outside personnel should be permitted to criticise a design from the standpoint of accessibility and the most favourable position for welding, and even to suggest modifications of design with those objects in view. It is true that a more practical appreciation of the difficulties of welding would be invaluable to a draughtsman, and a welding course such as the author recommends would do him no harm. He should at least familiarise himself with the general conditions under which welding is performed, and so design his structure as to provide for the best results. Such questions as allowance for contraction, and the sequence and procedure of welding which will avoid, or at any rate minimise, distortion and the locking up of undesirable stresses, are best solved as the result of experience. This will be mainly in the hands of the outside staff, but their records should be communicated to the Drawing Office, and the draughtsman should know sufficient of the practical aspect to apply the information so received.

I am glad to note that in the case of the "Helicina" specific instructions in regard to the welding procedure were sent out from the Drawing Office. This is now the general practice in most shipyards, and is a great step forward from the days when joints shown on plans were merely marked "weld," leaving it at that.

Would the author please state what distance was allowed between keel plates for the contraction of the butts, and whether these plates were pre-set upwards to counteract distortion?

The alteration made in the edge-preparation of the bottom shell plates, and which resulted in a reduction of distortion, is very interesting, but it is not very clear why it was effective. I would be glad if the author could enlighten us on this point. It may have been due to the ready fusion of the feather edge, thus virtually increasing the gap, or it may have been "just one of those things."

I would ask the author to say whether the upper deck plating seams and butts were all welded before the beams, transverses and girder were welded to the deck. Strictly speaking, of course, the welding of attachments and edges of upper deck should be progressive in that order, to allow for the contraction caused by the fillet welds, but it is appreciated that questions of economy and manning must be taken into account, and the case is parallel to that of welding the bottom structure to the bottom shell after the latter has been completely welded.

I read that the stringer sheerstrake connection was made last of all. May I ask whether step-back or other sequence was used here, and, if step-back, were full blocks of welding made at each step, or was a cascade step-back method adopted?

One last question. Were the butts and seams of side shell welded from the inside or outside, and what was the edge-preparation for the seams? Were both edges bevelled or only the lower edge of each plate?

This is a most interesting practical paper, and is valuable as representing what has been found by a firm with long experience of welding to be the most efficient and economical way of building. Other builders will, of course, have their own methods, dictated by their facilities and the special characteristics of the vessels under construction, but the general principles will be the same, and the author deserves the thanks of the Association for bringing them to our notice.

MR. A. G. AKESTER.

I have followed the builders' methods for so long, pretty well as outlined in the paper, that it is only here and there that changes are apparent. Thus the welding of butts, at least for the thicker plating, instead of being done from one side with only a final run overhead, is now proportioned two-thirds thickness down hand and one-third from underneath. This has evident advantages.

Also, instead of completing portions of bulkheads, &c., at the gantries, even to the final back run, which in those days meant turning over, the portions are now finished off by doing the sealing run in position at the berth.

I am glad to see that gouging on the reverse side is applied, for this is, I think, essential to-day with the use of heavy electrodes.

Welding schedules or specifications for all principal jobs, and a welding liaison draughtsman between Drawing Office and Yard have such manifold advantages that it is always amazing to me that so many yards do without them.

The burning out from the solid plate of the deck transverse complete with brackets is, I think, well worth while, and there is much scope for the use of the welded face flat here and elsewhere.

It is characteristic of the builders that they stick to their practice of welding instead of riveting the upper deck stringer plate to the sheerstrake, of having all butts free, and no intermittent welding in the main structure. With these arrangements, too, I am in general agreement.

I saw several of the Liberty ships with fractured shell and deck plating during the War, but as time goes on I think we will look upon these as "special" welding cases and not draw too many conclusions from them as being applicable to our own designs.

Just prior to the War notched stiffeners, or something corresponding to them, were introduced, and they are quite the vogue in Scandinavian ships to-day.

They are being used in tankers building at Greenock just now, and I think give certain advantages, but the bending caused by the notching is troublesome and has to be counteracted.

MR. D. TURNER.

In view of the importance of the human element in the welding of such a ship, and since merely a passing reference is made to the operators in the paper, it might be interesting, and no doubt helpful, if the author would tell us how the Surveyors satisfied themselves with regard to the qualifications of the welders and trained supervisors engaged in the welding of the strength members of this ship, and what methods, if any, were adopted to examine the finished welds.

MR. THOS. P. GIBBESON.

I would like to ask the author if the welders on ship work are subjected to any form of tests in order to show their efficiency, and if they are graded for certain classes of work. This practice is adopted on the engine side in order to ascertain that a welder is fully qualified to carry out a certain type of work, and a Surveyor has the right to know if a certain welder or welders have been subjected to these tests.

Another point I would like to enquire of the author is if X-ray plant is made use of in ship welding work, and, if so, on what seams? It might be extremely useful as a check up on the quality of the weld being deposited. I would suggest that the shell plate seam near the bridge, where weakness occurs due to change of section especially if there is a transverse bulkhead adjacent, might with advantage be X-rayed. There are undoubtedly severe stresses set up at this point when the vessel is hogging or sagging in a heavy sea. I understand trouble has been experienced in the Liberty ships at this particular seam.

Another joint which might be X-rayed is the connection of upper deck stringer plate to the sheerstrake, and, as the author remarks, this is a joint which requires careful attention and consideration, and an X-ray photograph would clearly show if the welding had been carried out satisfactorily.

Another part where trouble is often experienced is in way of corners of hatchway coamings, where cracks sometimes appear, and the X-ray plant might be usefully employed on these welds.

It is appreciated that there might be some difficulty in adapting a portable X-ray plant to the taking of some of these films, but no doubt this could be overcome with a little thought and ingenuity.

MR. H. R. GIBBS.

I was particularly interested in the description of the difficulties encountered during the welding of the flat bottom shell, and I think a comparison between the method used by the builders of the "Helicina" and that used by the builders of C3

Cargo Vessels for the Dutch Government recently completed in the U.S.A. would be of interest.

The procedure was as follows :—

The keel plates were laid on the keel blocks and the butts tacked. The flat bottom shell, comprising sub-assemblies of three plates (machine-welded in shop) were then laid into position on supports, tacked, and the complete bottom shell as laid was then strongbacked as follows :—

10 in. by 8 in. I beams were fitted adjacent to each transverse butt of the A, B and C strakes and were continuous across the bottom from bilge to bilge. At each end of the above strongbacks shorter ones about 8 in. to 10 in. long were secured in a fore and aft direction on the outer edge of the C strake.

Three short intermediate transverse strongbacks were then fitted equidistant between each of the long strongbacks, and these extended across the keel and about half the width of A strake.

The strongbacks were secured into position with the usual clips and wedges, and the butts of the shell plating were fitted with 6 in. by $1\frac{1}{2}$ in. by $\frac{3}{8}$ in. flat bar saddles spaced about 12 in. apart placed across the joint on the under side. These saddles allow desirable freedom in both directions, and were used during welding in lieu of the tacks, which were then removed from the transverse butts of the A, B and C strakes and the keel to A strake.

After the keel was completely strongbacked the tacks were burnt or chipped out of the keel butts, the proper bevels replaced and production welding proceeded as follows :—

(1) Keel butts welded, commencing from amidships and working towards ends.

(2) Transverse butts welded, starting at keel and working outboards.

(3) Keel to A strake welded, commencing at amidships and working towards ends and welding both sides simultaneously.

As soon as a butt was completed the flat bar saddles underneath were removed, the first downhand run back chipped to good metal and the overhead sealing run welded. Small gauge electrodes were used for the first run of the downhand welding, the succeeding runs by large gauge electrodes. All welds were back stepped in steps not exceeding 2 feet.

The above procedure resulted in a very fair bottom shell, which, in my opinion, is an important essential to the subsequent fairness of the remainder of the structure.

The author's remarks about the welded connection of the sheerstrake to the stringer plate are interesting. This connection is one of the most important and most valuable joints in a vessel, whether welded or riveted, and as such should be treated with the utmost respect and care. It is a joint which, owing to its inaccessibility underneath, is most difficult to weld. According to Fig. 11, two sealing runs were applied, and in such a case I think it is practically impossible to back clip or gouge out the first downhand pass in a proper and efficient manner, owing to the confined space and the proximity of frame ends and brackets. The present tendency is to fit a riveted stringer angle which, in the event of a fracture developing in either the deck or the shell, would act as a most convenient barrier to its further progress.

MR. H. L. WALKER.

On page 1 there is a Typical Welding Specification in which one of the columns is set aside to record the size of the weld fillets in terms of throat thickness. The Society's regulations, except in the Metric Rules, indicate the leg size of fillet welds. Could the author indicate if it is the continuing practice of the builders to state weld requirements on their working drawings in terms of throat thickness?

On page 2 reference is made to unfairness in the bottom shell of an earlier sister vessel. Could the author offer further information upon what is meant by the bottom shell fairing itself out when the longitudinal stiffening members were erected and welded down? Did this not incur a large amount of screwing and fairing so that faying surfaces were obtained for the stiffening members? Could the author also indicate if the plate-end butts of the keel and/or the bottom

shell were set up prior to welding, in any cases, with a view to final fairness?

On page 4 the erection sequence of the main structure is indicated, but it would be of interest to know why the upper deck longitudinals were erected before the upper deck transverses.

Referring next to Fig. 6, which shows that panels A, B and C were welded to the bottom shell before they were connected to each other by welding of the overlap butts, could the author state any special reason for this sequence?

From Fig. 10 it is observed that at the top of the sheerstrake there are two parallel welded joints within three inches of each other, extending the full length of the vessel, port and starboard, namely, the joint of the upper deck stringer to the sheerstrake and the top edge of the sheerstrake to the erection sides or bulwarks. Had the "Neverita" and "Olna," referred to on page 3, these parallel joints so near to each other, and were any special procedures arranged for the welding of the butts of the erection sides or bulwarks in addition to filing and buffing of certain welds after completion, as mentioned on page 4 of the paper? Could the author also indicate what were the welding arrangements and procedure where the shell seams crossed the faying flange of the side frames, what allowances were made in the preparation of E strake for welding of last shell seams, D to E and then E to F, and if the side frames were riveted to shell before seam E to F was welded?

It would certainly be of interest if the author could make mention of the reason or reasons which have caused the builders to adopt continuous fillet welding throughout the vessel, except for a few minor items, make comment upon the time taken to build the vessel and of a comparable vessel of largely riveted construction, and the time taken to test the tanks of this vessel and a similar vessel of riveted construction with, perhaps, his observations upon the results of these tests.

Finally, Mr. President, it is desired to express thanks to the author for his work in the preparation of his paper and its presentation this evening.

MR. J. STILEMAN.

I would like to know whether hand-welding was used for choice or of necessity for lack of equipment. That is: to know whether the builders considered hand-welding to be preferable to any of the mechanical welding plants.

REPLIES.

I am gratified to know that the paper on the oil tanker "Helicina" has been appreciated and will be of use to colleagues in general, and I wish to thank those who have contributed to the discussion, and have shown such a lively interest in the fascinating problem of welding.

To Mr. R. B. Shepheard.

The answer is: No distortion effects resulted from the sequence described in the paper of welding the double bottom tank members. I suggest the narrowness and comparatively small panels, and thickness of the tank top plates, in comparison with the normal double bottom structure failed to be influenced by the fillet welding. However, the method described which overcame the hogging effect has been carefully noted with much interest.

To Mr. J. S. Ormiston.

It has been found by experiment that the unsymmetrical double vee to the extent of two-thirds and one-third for plating ·75 in. and over provides a preparation which gives the minimum amount of distortion, and can be welded without pre-setting the plates, and with this arrangement the overhead welding is cut to a minimum. A sectional view of each run of the double vee is shown in the figure.

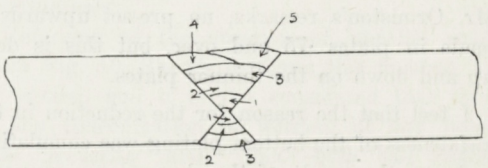


Fig. 1.

Flame cutting for the vee preparation is common and good practice, and I fear my reference to flame cutting of joints of plates which are in place either too tight or unfair is a misuse of the phrase. What I meant to convey was that a burner having to deal with this sort of error at the ship is to be discouraged, as it involves burning and in many cases fairing the burnt edge with a pneumatic tool, and, as a rule, the resultant preparation leaves much to be desired. The length of this particular vessel did not show any shortening. No lifting of the ends occurred in any of the vessels built, and no particular precautions, in the shape of tackle, had to be used.

With regard to the connection of the upper deck stringer plate to the sheerstrake, Mr. Ormiston is obviously looking for the best method to give freedom, with which I entirely agree, and the methods adopted, namely, to leave the riveting of the frames to sheer and all connections to the deck stringer inside the tanks plus frame knees to deck to be completed after the welding of the joint appeared to give all the freedom necessary.

To Mr. F. C. Cocks.

I am appreciative of the remarks by Mr. Cocks regarding the importance of co-operation between the Drawing Office and the Shipyard in arranging details and welding procedure, and I feel colleagues would do well to follow this advice, and suggest efforts be made at Shipyards where this co-operation is not too evident, and where welded vessels are being constructed, to get the Management to give this matter serious consideration.

This yard, after many experiments, now lay keel plates in their exact length, leaving the first butt to be welded with a gap of $\frac{1}{8}$ in. This proves in practice that if six keel plates 30 ft. long are laid as stated, the finished job is 180 ft. to within a fraction. As stated in answer to Mr. Ormiston's remarks, no pre-set upwards is made in plates ·75 and over, but this is done up and down on the thinner plates.

I feel that the reason for the reduction in the unfairness of the bottom plating was cumulative, and was the result of the changed vee preparation, plus the alteration in the method of welding plus some strongbacking similar to that described by Mr. Gibbs in his contribution to the discussion.

The upper deck plating was dealt with as individual members, and as the butts and seam were completed covering a tank length, so the underside connections were completed, all fillets, the welding finishing 12 in. to 18 in. short of the unwelded seam.

The stringer sheerstrake connection was all done with straightforward manual welding and no step-back methods were adopted.

The butts and seams of the side shell were all welded from the outside, and the edge preparation for the seams was a 60° vee with $\frac{1}{23}$ in. 60° vee on the inside edge—feather edge—for sealing run.

To Mr. A. G. Akester.

I was very pleased to read Mr. Akester's remarks, as I know and appreciate that in many respects the ability of the builders to produce what he calls "a great achievement" is due in no small measure to his interest in the pioneering work of this firm. I may add that notched stiffeners are being introduced in the latest tankers now building by Swan Hunters.

To Mr. D. Turner and Mr. Thos. P. Gibbeson.

Mr. Turner and Mr. Gibbeson have asked questions which an author of a paper such as the one under review might expect, and I will do my best to give the facts as I have experienced them.

When an employee applies for a job as a welder in this yard he is tried out to ascertain his ability. If his work is only moderate he will, if he agrees, be sent to work in a welding school in the yard where work is done on articles of minor importance. From time to time his work is tested, and if he shows improvement he is given, in stages, work of more importance, until he finds himself in due course among those welders who, from time to time, are graded to suit the work for which they seem most fitted. If, on the other hand, no improvement is shown at all, he is told he has no prospects of ever becoming a welder, and it is suggested to him

that he should consider some other trade. As these welders are tested by the yard from time to time, the Surveyor does have an opportunity of seeing the work turned out by the men and gets to know them. The yard have quite a number of men who are what are called "all purposes men," i.e., can weld in any position, in the same manner as an electrode is graded as an all purposes rod. Regarding Supervisors, this firm has been welding for many years now, and when the pressure was put on for as much welding to be done as possible in all shipyards, the builders had available a number of skilled and experienced men whom they had trained themselves and who were well equipped for this important work.

With regard to Mr. Turner's question regarding the examination of the finished welds, there seems to be very little one can do other than to check current, length of deposit, leg length of fillets, and the general appearance of the weld and an occasional cut out for visual inspection.

Regarding X-ray, raised by Mr. Gibbeson, the Admiralty have from time to time had a plant in this yard for the examination of welding on Royal Navy vessels, and I have had the opportunity of seeing many films of the work produced by the welders of this yard, but, unfortunately, the time could not be spared for photographs to be taken of the Merchant work. I understand that the Society is taking this matter of X-ray up seriously, and I for one hope in the near future it will become part of the Surveyor's normal duties. A number of the important shipbuilders in the country, I believe, are hoping to have plants installed in due course.

All the joints which Mr. Gibbeson mentioned would be all the better for being X-rayed.

To Mr. H. R. Gibbs.

The description of the methods used by the builders of C3 cargo vessels for the Dutch Government in U.S.A. for dealing with the bottom shell plating is very interesting, and I thank Mr. Gibbs for this information. The pooling of ideas which have proved satisfactory, especially in connection with welded vessels, is, I feel, very necessary in a society such as Lloyd's Register, and this is an instance which I am sure will be welcomed by colleagues dealing with this type of work.

Mr. Gibbs will be interested to know that Swan, Hunter's now adopt a modified form of strongbacking as detailed by him with satisfactory results. (See also reply to Mr. Cocks.)

With reference to the last paragraph, I can assure Mr. Gibbs that in spite of the, what I will call, rather cramped conditions, every foot of the underside of the sheerstrake deck stringer connection was gouged out and two overhead sealing runs applied. Both Management and foreman realise the necessity for this, and great care is taken in dealing with it.

To Mr. H. L. Walker.

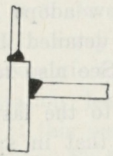
Since the introduction of Lloyd's Rules for Electric Welding in their present specific form, the builders have introduced leg length sizes for fillet welds, plus throat thickness.

Regarding the unfairness of the bottom shell, referred to on page 2 of the paper, will Mr. Walker visualise a large area of steel such as this bottom plating presented when the butts and seams were welded complete, only supported from underneath by shores and an odd strongback above. It was apparent when the first panels of the longitudinal bulkhead were erected that this large area, with adjustment of shores under, was amenable to remain fair as was required. Certainly some pressure had to be resorted to by screwing down at odd places, but this was not general. No pre-setting of the plate end butts was made.

With regard to the erection sequence of main structure, on page 4, I regret a clerical error has occurred here, and the upper deck transverses were erected before the upper deck longitudinals.

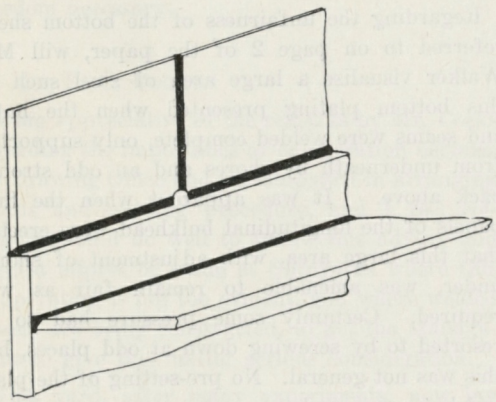
Referring to the question of parallel welds from Fig. 10, Sketch A shows this finished job in section, and it is not considered that there is any concentration of welding at any point. The "Neverita" and "Olna" both had similar joints to this one. No special procedures were

arranged for the welding of the butts of erection sides and bulwarks, but, see Sketch B, a hole was punched at the bottom of the butt welds of bulwark plates. No special arrangements were made where the shell seams cross the faying



Sketch A.

flange of the side frames; the preparation of the edges is as stated in the answers to Mr. Cocks' contribution and the $\frac{3}{32}$ in. V preparation against the frames was sufficient to give the necessary penetration into the frame flanges. No special allowances were made in the preparation of E strake for welding the last seam E to F, the curved nature of this strake of plating gave the necessary freedom. The side frames were partly riveted to the shell before seam E to F was welded.



Sketch B.

At the time this vessel was in the design stage the Management were not convinced that intermittent fillet welding was a satisfactory method for oil tank work. Between that period and the present, and with the publication of the Society's latest Rules for Electric Welding, intermittent fillet welding is now being carried out in this builder's yard. Proposals were put up to the Owners, the Anglo-Saxon Petroleum Co., that a sister vessel to the "Helicina" should be welded on the intermittent principle, but was turned down by them. This vessel is now under construction on the full fillet principle.

"Helicina."—Keel laid 5th January, 1945. Completed middle October, 1946.

A 500 ft. tanker, all riveted, except transverse and longitudinal bulkheads.—Keel laid 5th April, 1945. Completed end October, 1946.

"Helicina."—Started testing oil tanks 18th February, 1946; completed 16th March, 1946.

500 ft. tanker.—Started testing oil tanks 4th June, 1946; completed 27th June, 1946. No week-ends worked.

Perhaps the most important observation which one can make on the tests is: Freedom from leakage in way of all welds.

Instructions are given to all caulkers attending the tests that unless there is a leak of major dimensions affecting the test, no punching up is to be done until the Surveyors have had an opportunity to assess the gravity of the fault and whether punching up can be accepted or the welding cut out and rewelded.

I should imagine from the builder's point of view, the costs in connection with the testing out of a ship of this description are much less than a similar riveted vessel.

From observation when the plugs are drawn on deck to release the pressure, expansion seems pretty much the same as a riveted vessel.

Distortion on the bulkheads while under pressure is generally very slight.

To be somewhat flippant: Freedom from the ever-present Sawdust as in a Riveted Vessel.

To Mr. J. Stileman.

Up to the time of the re-introduction of the "Fusarc" machine the builders were not convinced that mechanical welding was preferable to hand welding. However, the "Fusarc" machine is now in general use, and as research goes on and as new semi- or wholly-mechanical plants are evolved, the Management are alive to the fact that they can be used to advantage.

Further Contribution to the Discussion of Mr. E. H. Dean's paper "THE CONSTRUCTION AND DETAILS OF THE WELDED OIL TANKER 'HELICINA'."

By Mr. A. W. JACKSON. and the Author's Reply.

MR. A. W. JACKSON.

The author is to be congratulated on the laudable idea of placing on record the welded construction of a large oil tanker.

I am in agreement with him regarding the training in welding technique of ship drawing office personnel and students in Naval architecture.

Could the author tell us why a panel system was used on the bottom, yet the old riveted type of brick system of butts was used on the deck?

The author somewhat grudgingly admits that there were welding worries during construction, but I think that the paper would have been more helpful if details of the difficulties overcome had been included.

Could he tell us how brackets, vertical stiffeners and horizontal girders were kept lineable on opposite sides of the individual bulkheads to prevent couples being set up, and whether any fracturing was experienced after welding "E" seam of shell plating?

From the point of view of speed in construction, how were the welders positioned as regards the shell butts? Was it necessary to hold dry surveys of the tanks before testing to ensure that all welding work had been satisfactorily completed, especially the overhead and vertical welding done after assembly of the large fabricated portions?

From my own experience, dirt in the tanks does tend to make a thorough examination difficult.

I notice that no intermittent welding of stiffeners has been done except in the case of minor bulkheads, etc.; continuous welding is surely a very expensive method of construction. Could the author tell us the reason for its adoption?

As the author remarks, it is a sin for any burner to have to correct a joint after it has been planed and properly veed. Too often a perfectly good joint has been spoiled by injudicious burning and inadequate chipping in position.

I feel that burners, platers and carpenters would also benefit by a welding course.

Due to poor plating and bad burning, the welder is left in much the same position as the riveter in the riveted ship; he, with the aid of the caulker, has to make the job as good as possible.

One thing the author had not to bother about—his was not a combined welded and riveted job, which from a Surveyor's point of view leaves a lot to be desired as it requires much more inspection to ensure that welding takes place before riveting.

On the whole I think it would be a good thing if the author wrote a second paper from the practical aspect of the all-welded ship, and I look forward to seeing it in the next syllabus of the Association.

REPLY TO MR. A. W. JACKSON.

With regard to the question in paragraph 3 referring to the panel system of bottom plating—it has always been the practice of the Owners, The Anglo-Saxon Petroleum Co., to double up the bottom plating in way of transverse bulkheads, this method would have been difficult to carry out in all welded construction,

so the transverse plate was fitted on the bottom and thickened up to comply with the Owner's wishes.

The welding worries referred to really occurred in the building of the "OLNA", the first of this type of vessel; due note of these was taken and in the building of the "HELICINA" the difficulties were nearly all eliminated.

Paragraph 5 dealing with lineable parts of the structure on opposite sides of bulkheads—the answer is very careful lining off, which I feel gives emphasis to Mr. Jackson's reference to burners, platers and carpenters benefiting from a course in welding, with which I agree. The fact that the bulkheads are built on the ground does enable these members to be carefully positioned, and as the stiffening in the tanks is designed with alternately stiffeners and plain tanks, this method lends itself to a satisfactory finish. There were no fractures during, or after, the welding of "E" seam of shell plating.

Regarding the positioning of welders doing shell butts—the various strakes are erected as numbered on the figure showing shell plating. After the starting butt is welded at amidships on the strake to be completed first, two welders can be positioned to work out this strake fore and aft, and at the same time the butts of the other strakes can be worked, taken in rotation in the same manner, always following on above and below the first strake, which means, of course, that the platers and hangers must be well in hand with their part of the job to keep the welders employed. Dry surveys of the tanks is very necessary before testing, and as much as possible of this work should be carried out by the Surveyor, the Owners' man and the yard searcher together. This combination was always available on this particular ship, and enabled the dry surveys to be carried out expeditiously, the yard searcher being, usually, a trained welder and charge hand. I agree, dirt in the tanks can be a very irksome factor, especially in the bottoms, and it is only overcome by the work being carried out in such a manner that each tank is so constructed and manned that all detail work is completed at the bottom and can be examined before the top structure has too far developed.

As regards continuous welding, I would refer Mr. Jackson to my answers in Mr. H. L. Walker's contribution which I think deal with his questions.

I feel Mr. Jackson's request for a second paper on the more practical aspects of the all-welded ship will have to be much deferred with conditions as they are at the moment.

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1947.

LLOYD'S REGISTER STAFF ASSOCIATION.

ANNUAL GENERAL MEETING.

MINUTES.

The Annual General Meeting of the Association took place on Monday, the 28th April, 1947, in the London Office.

The President, Mr. Shepheard, was in the Chair.

The Minutes of the last Session were read and adopted.

The Secretary read the financial statement as follows:—

	£	s.	d.
Balance in bank from the Session 1938–39	9	19	6
Withdrawn 23/3/47 for gratuities for messengers, &c.	4	0	0
Balance in hand, 28/4/47	5	19	6

The account had been audited and found correct by Mr. J. M. Murray.

The President then briefly addressed the meeting, giving a summary of the work of the Association during the Session. This year had been one of reconstruction, and he felt that the Association might congratulate itself on having made a good start.

For the coming Session the Association had been promised a good variety of papers and it was hoped that the new Session would be a full one. Mr. Sladden had agreed to open the Session with a paper on "Classification Procedure" which would be of value to members, and it was also hoped to have one or two special lectures.

The President expressed his thanks to the Hon. Secretary and others who had helped to make the Session successful.

ELECTION OF OFFICERS.

Mr. Murray expressed his warm appreciation of the work of the President and the Hon. Secretary during the year that was now closing, and added that he knew that he was voicing the opinions of the outports expressed in many letters. He proposed that these officers should be re-elected for the coming year. This proposal was seconded by Mr. Ferguson and carried with acclamation.

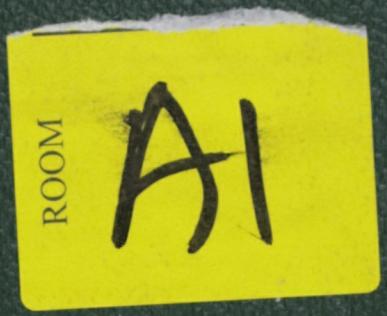
The President then expressed his appreciation of the honour bestowed on him by his re-election and agreed to hold office for another year.

The Hon. Secretary also thanked the meeting for his re-election.

Mr. Ferguson, seconded by Mr. Walker, proposed that those members of the Committee who were eligible for re-election should be re-elected. This motion was carried unanimously.

Mr. Pemberton proposed that Mr. S. Archer should be elected to the Committee to take the place of Mr. Munton who had now left the Staff. This proposal was seconded by Mr. Bunyan and carried unanimously.

This terminated the proceedings of the meeting.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